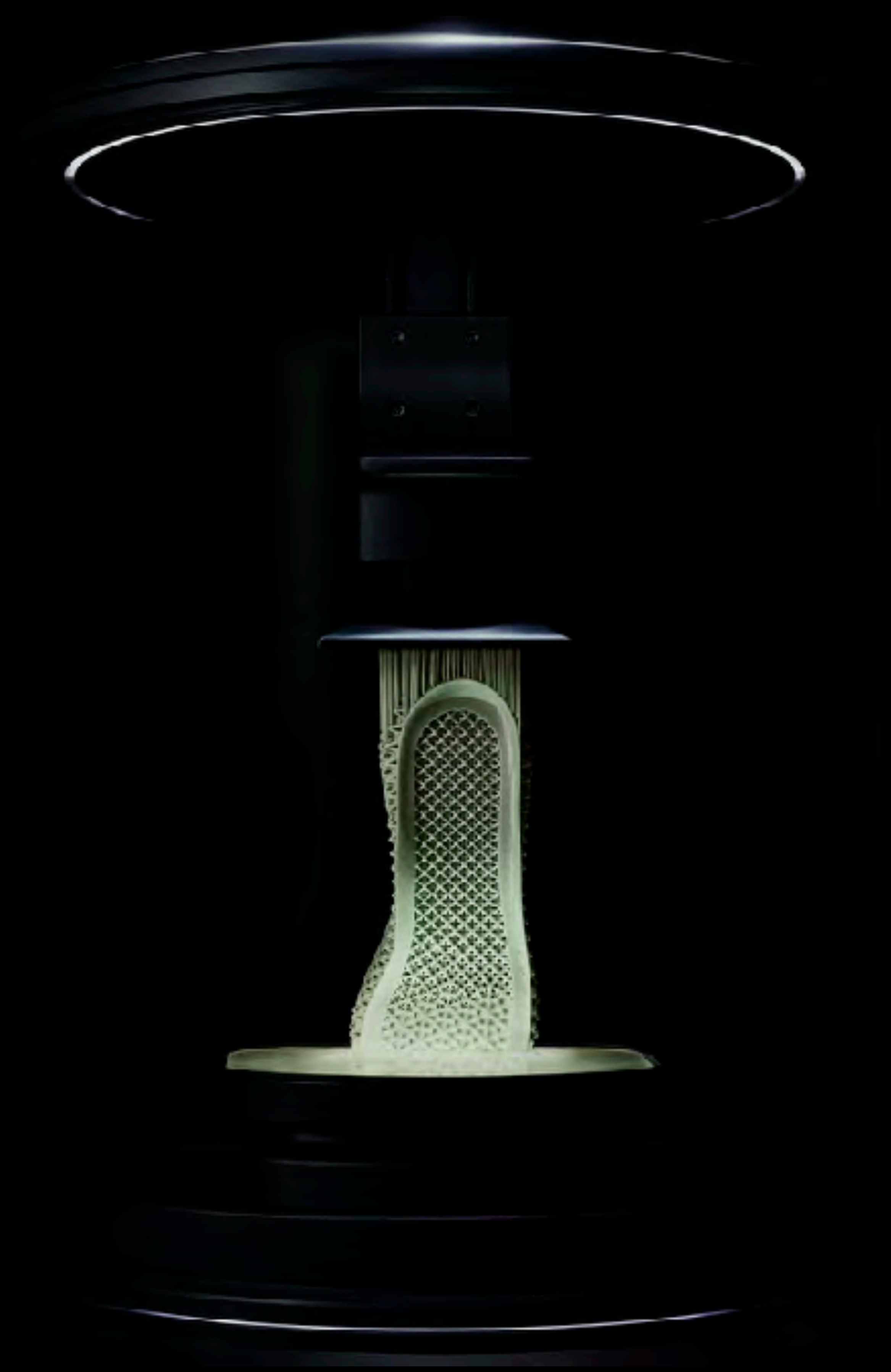
Carbon®

Joseph M. DeSimone, PhD
Co-founder & Executive Chairman



The 15th US-Japan Symposium on Drug Delivery Systems
December 16, 2019

FOUNDED IN 2013
Headquartered in
Redwood City, CA

$680M INVESTMENT
$260M series E completed in
June 2019 at a $2.46B valuation

APPROACHING
500 EMPLOYEES

> 300 PATENTS & PATENT
APPLICATIONS
55 issued patents

About Carbon

KEY INVESTORS

SILVERLAKE

G/

TEMASEK

MADRONE CAPITAL PARTNERS

Fidelity INVESTMENTS

Johnson & Johnson

Emerson Collective

ARCHina Capital Partners

BAILLIE GIFFORD

BMW

JSR

Nikon

adidas

GE

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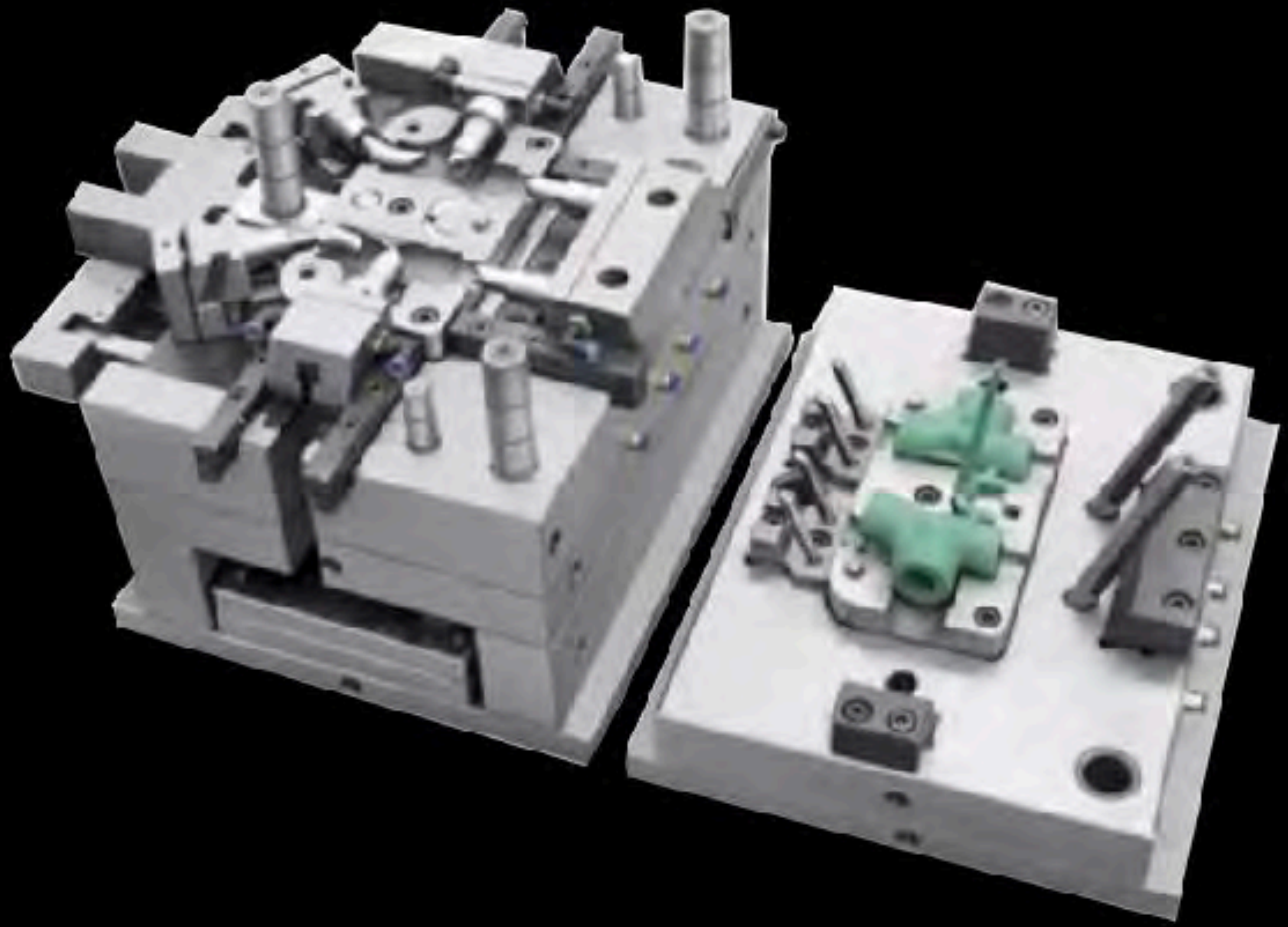
Joseph DeSimone
Co-Founder & Executive Chairman,
Carbon

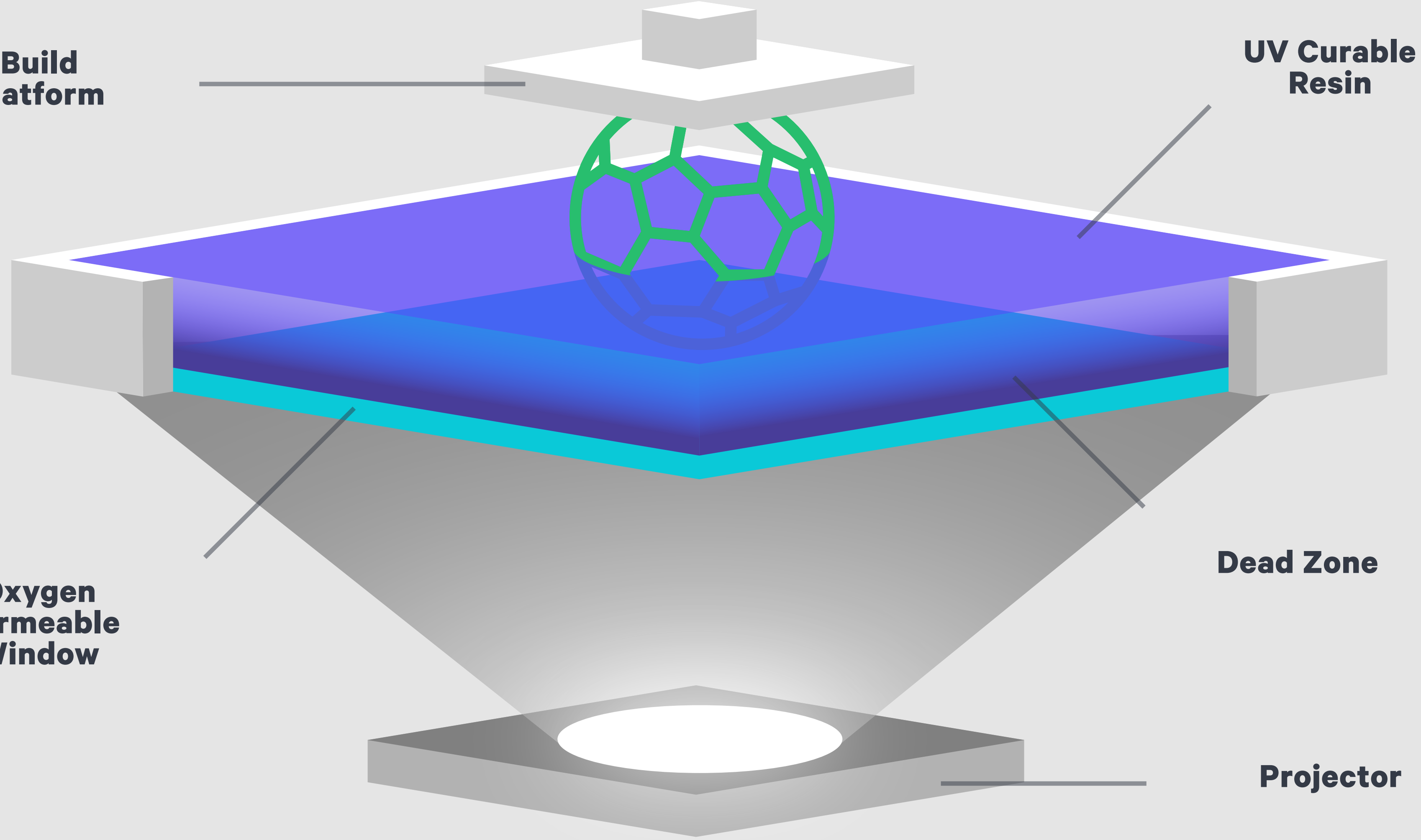
Casting / molding was invented 7,000 years ago



Injection molding $330B

Terminator 2: Judgment Day
Tri-Star Pictures

Science **2015**, *347*(6228), 1349-1352



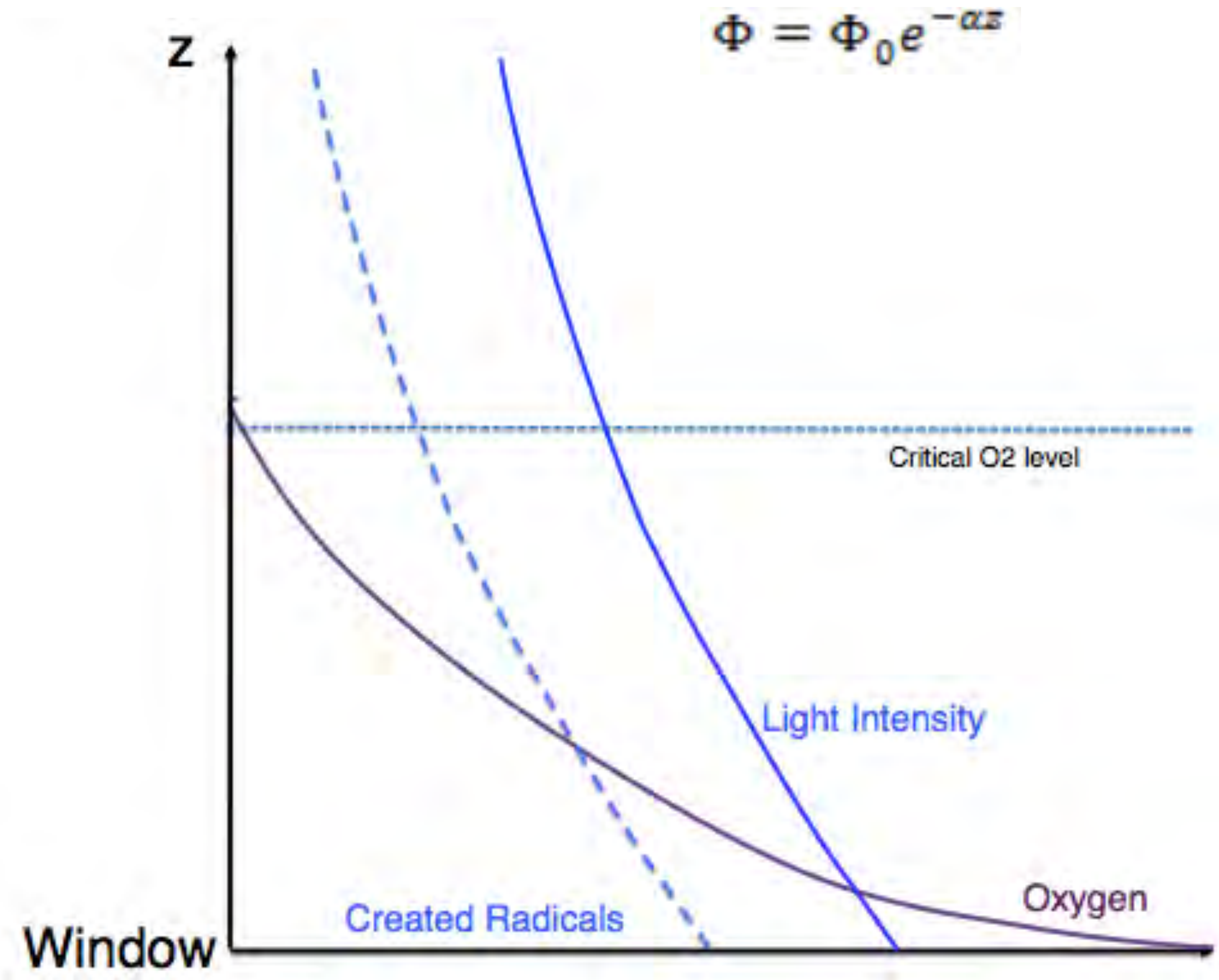
What would be the best “window” to support the liquid resin?

1. Rigid solid?
2. Flexible film?
3. Liquids (immiscible fluids)?


Carbon
Carbon


Carbon

At the Interface



$$PI \xrightarrow{hv} PI^* \xrightarrow{k_d} 2R\cdot$$

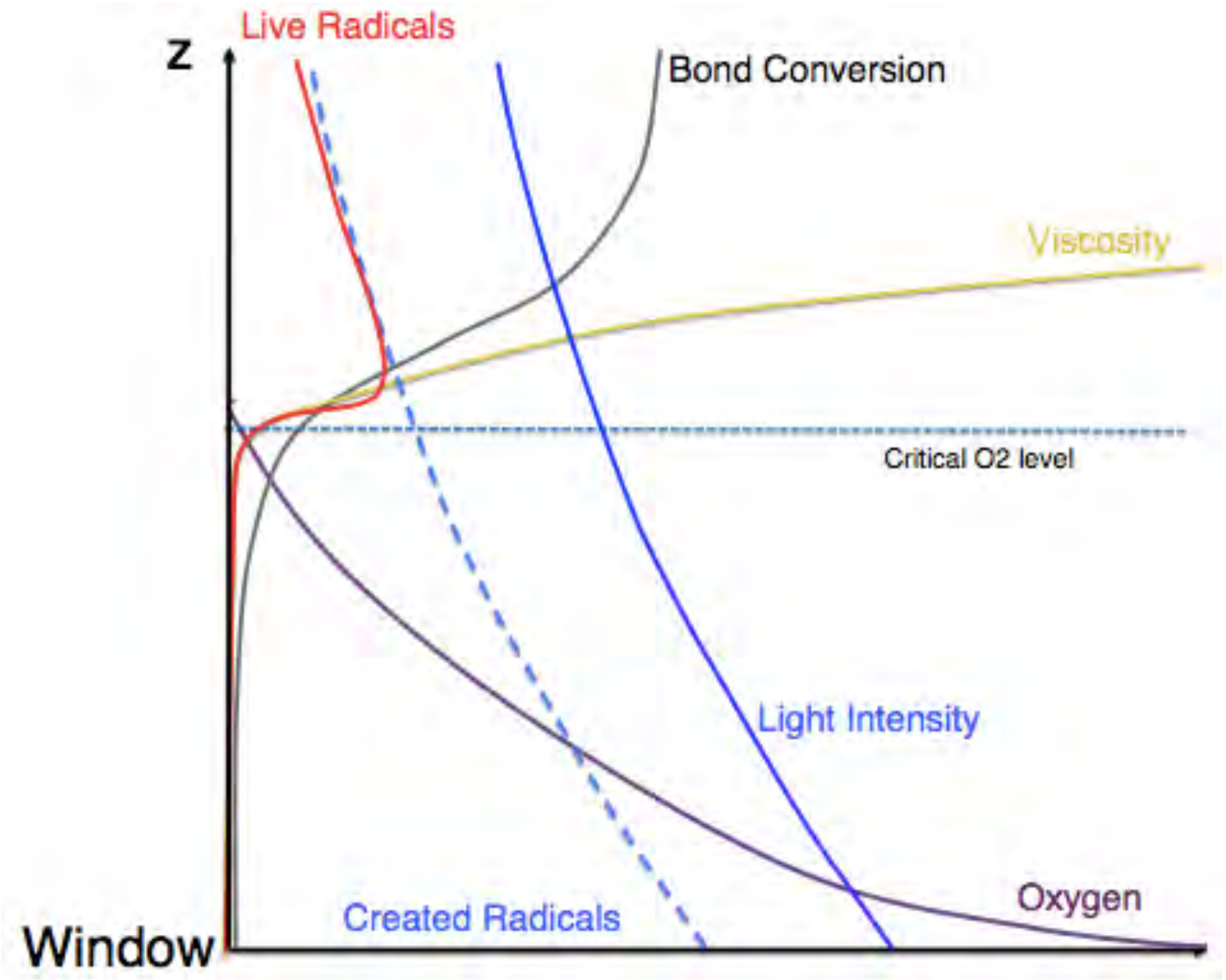
$$R\cdot + M \xrightarrow{k_i} RM\cdot$$

$$RM_n\cdot + M \xrightarrow{k_p} RM_{n+1}\cdot$$

$$PI \xrightarrow{hv} PI^* + O_2 \xrightarrow{k_Q} Quenching$$

$$RM\cdot + O_2 \xrightarrow{k_O} RMOO\cdot$$

At the Interface



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$$PI \xrightarrow{h\nu} PI^* + O_2 \xrightarrow{k_Q} Quenching$$

$$RM\cdot + O_2 \xrightarrow{k_O} RMOO\cdot$$

Print planner

Resin properties

- Dose-to-cure
- Molar absorptivity
- Viscosity
- Green strength of resin

Machine configuration

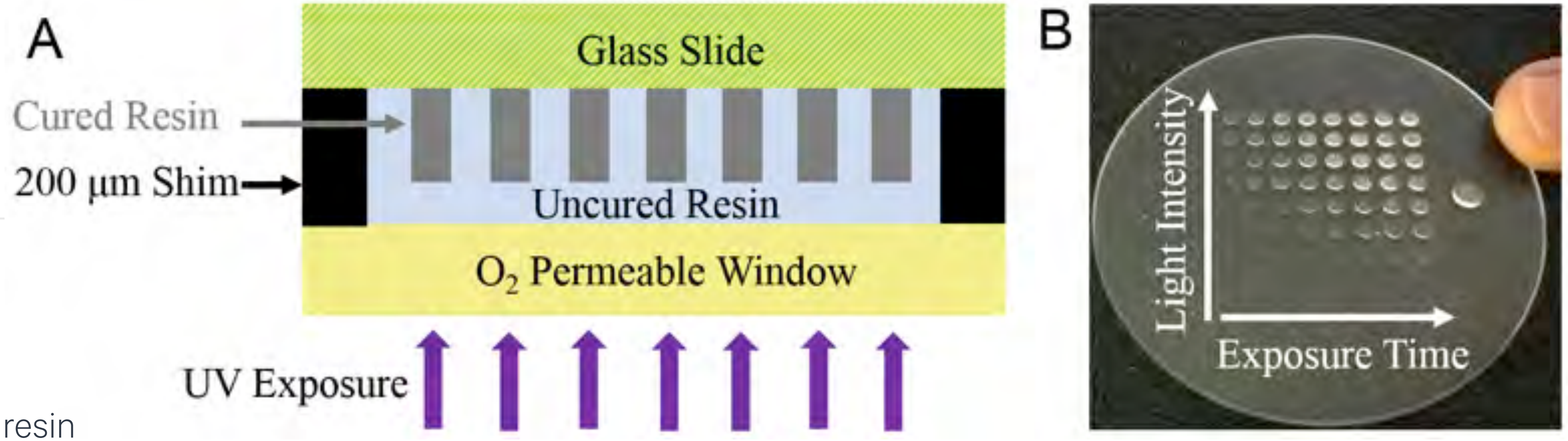
- Available light intensity
- Oxygen flux
- Pixel size

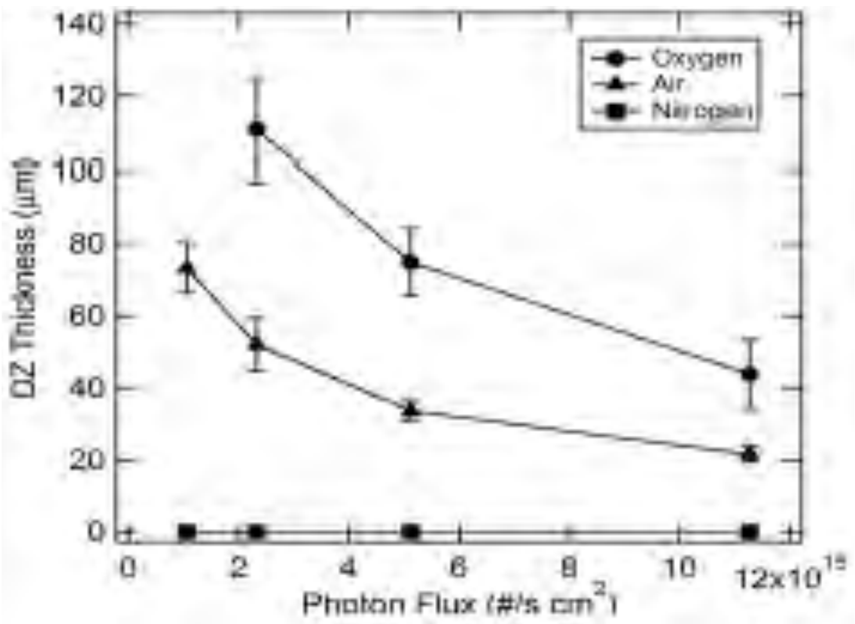
Part geometry

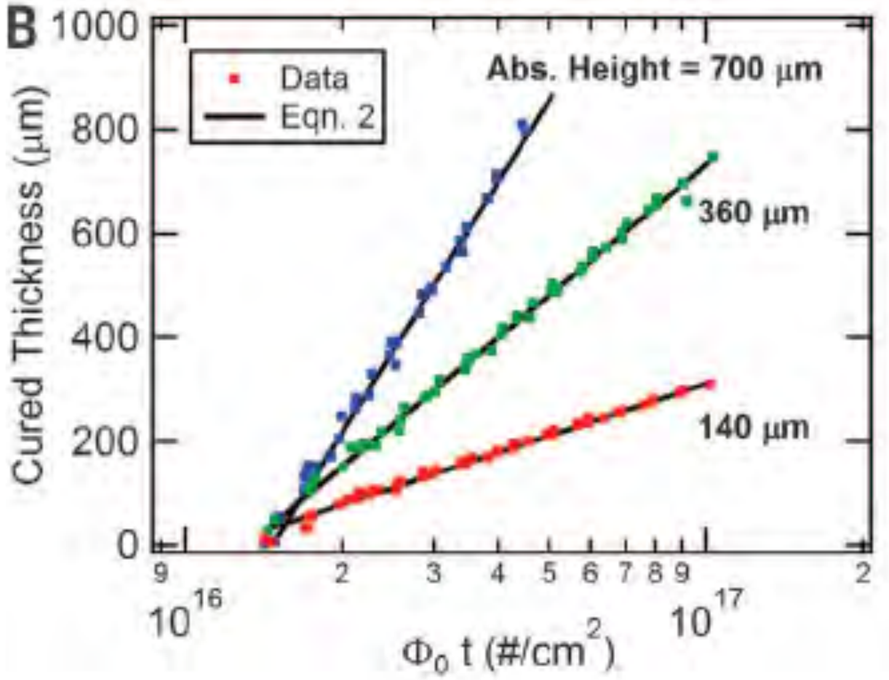
- Cross-sectional area
- Cavities
- “Hero” surface orientation

Desired operating conditions

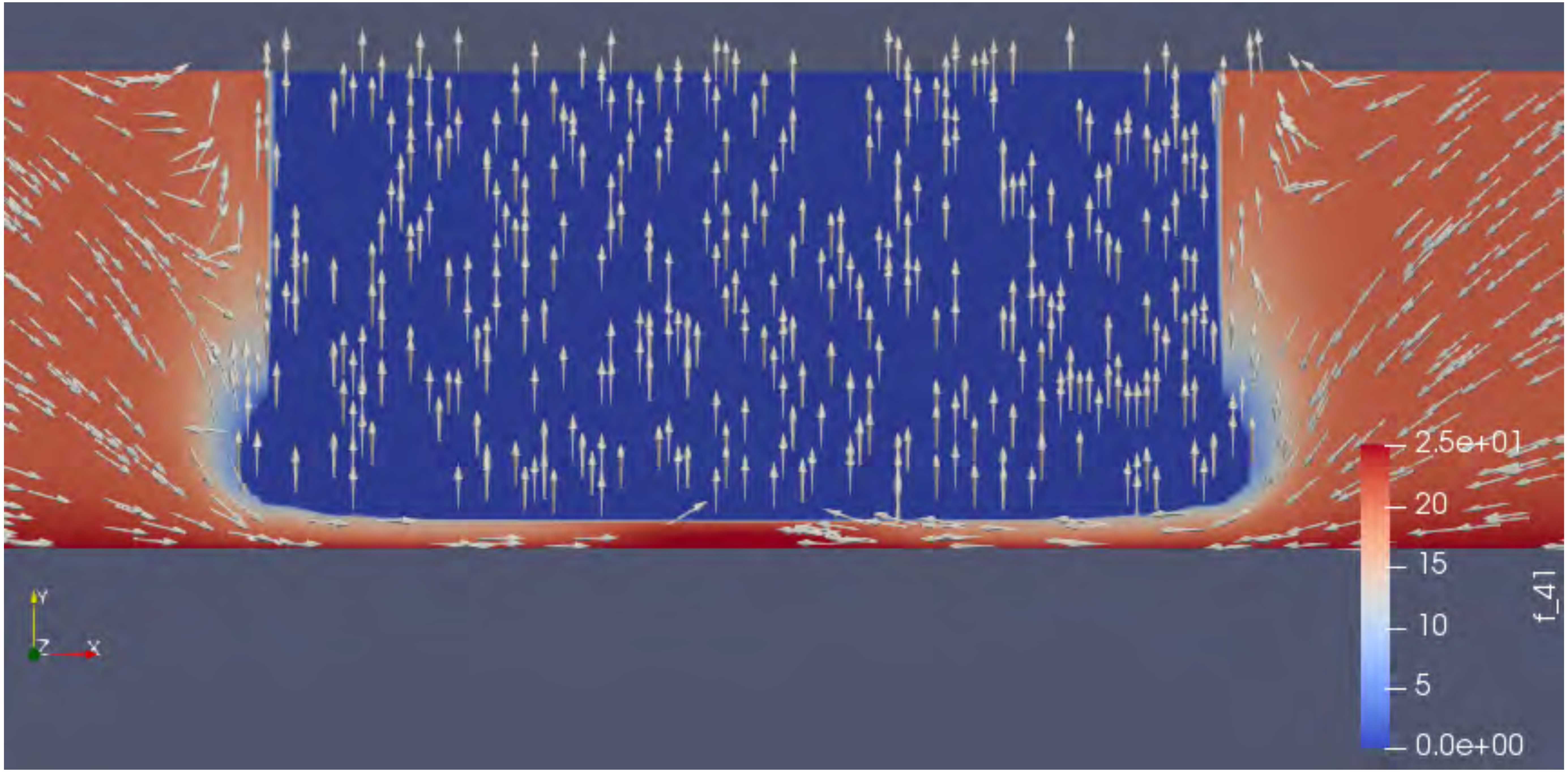
- Accuracy
- Trade-off between resolution and speed
- Use of latent heat
- General Purpose Printer mode vs Manufacturing mode



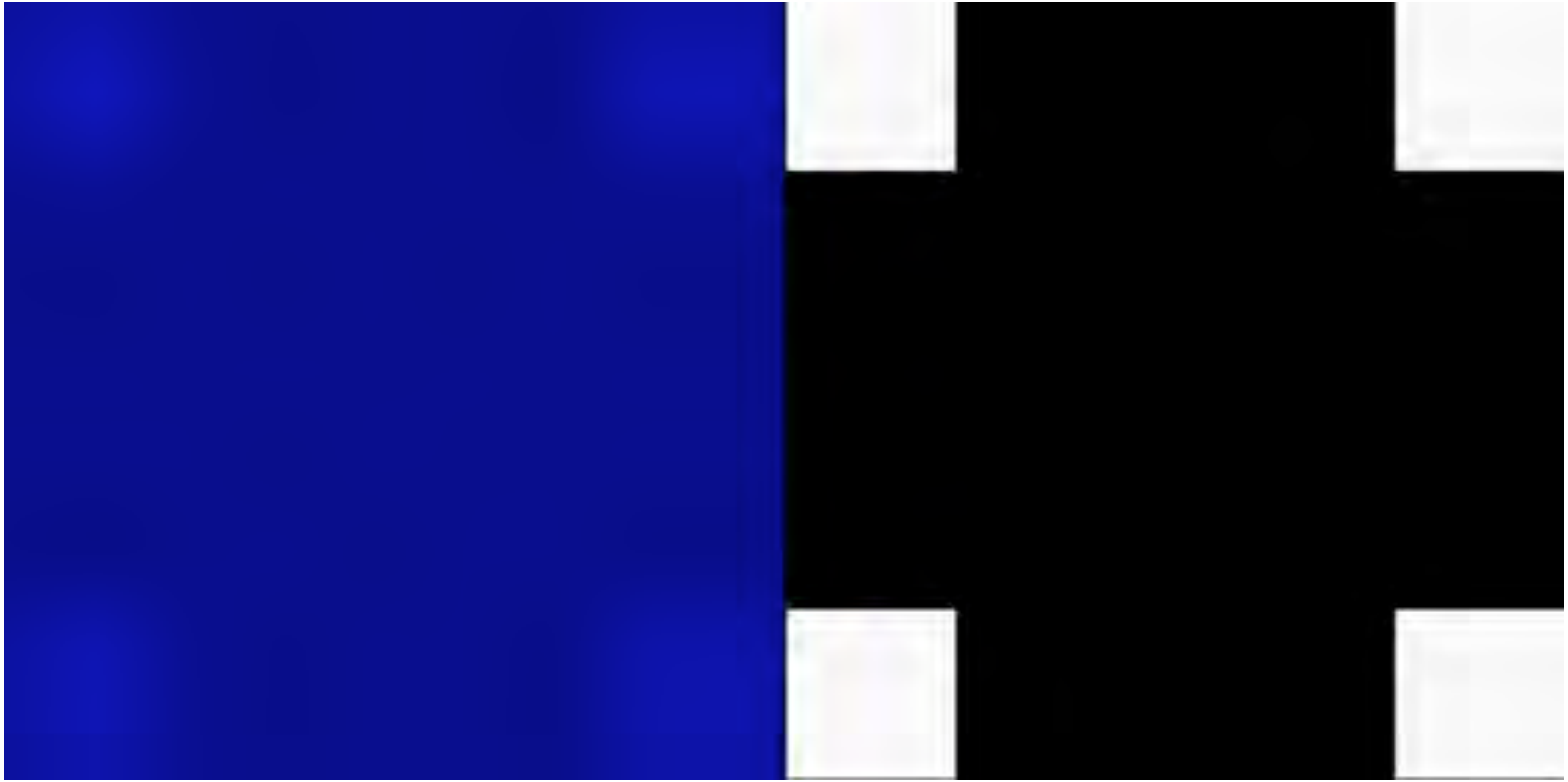




FEA simulation: O_2 and resin flow

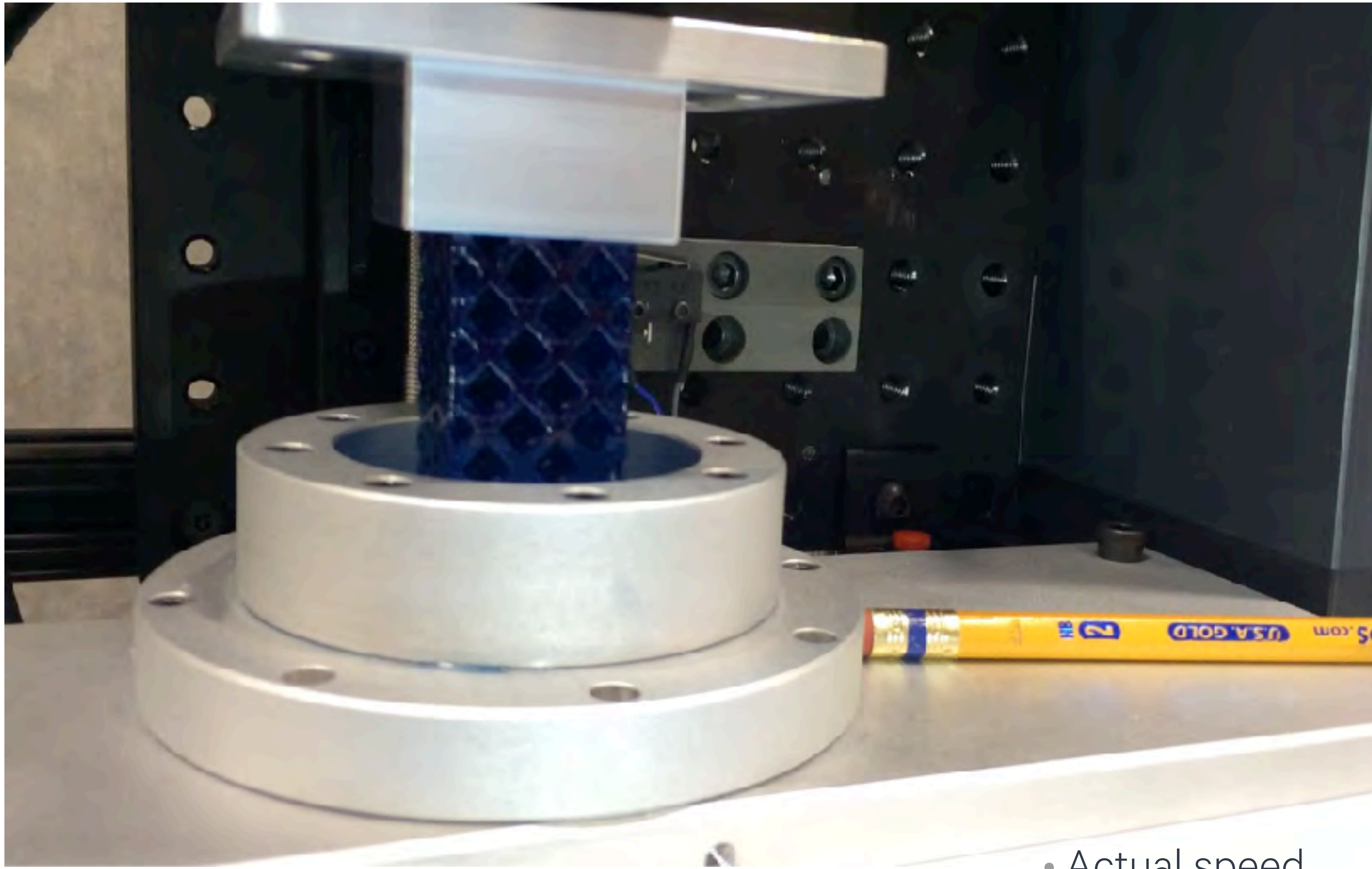


HEAT ORACLE



Factory of the Future

- Significant build speeds with CLIP
  - Demonstrated 2000 mm/h (79 inches / h)
  - High light intensity
  - Tailored resins
  - Exploit latent heat



- Actual speed

Print planner

Resin properties

- Dose-to-cure
- Molar absorptivity
- Viscosity
- Green strength of resin

Machine configuration

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- Oxygen flux
- Pixel size

Part geometry

- Cross-sectional area
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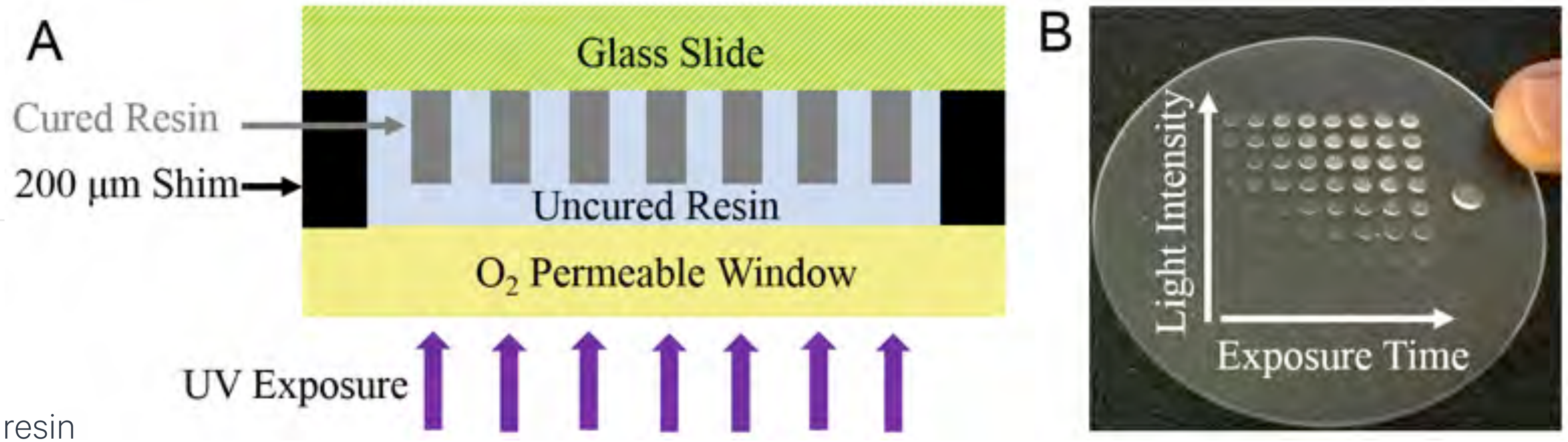
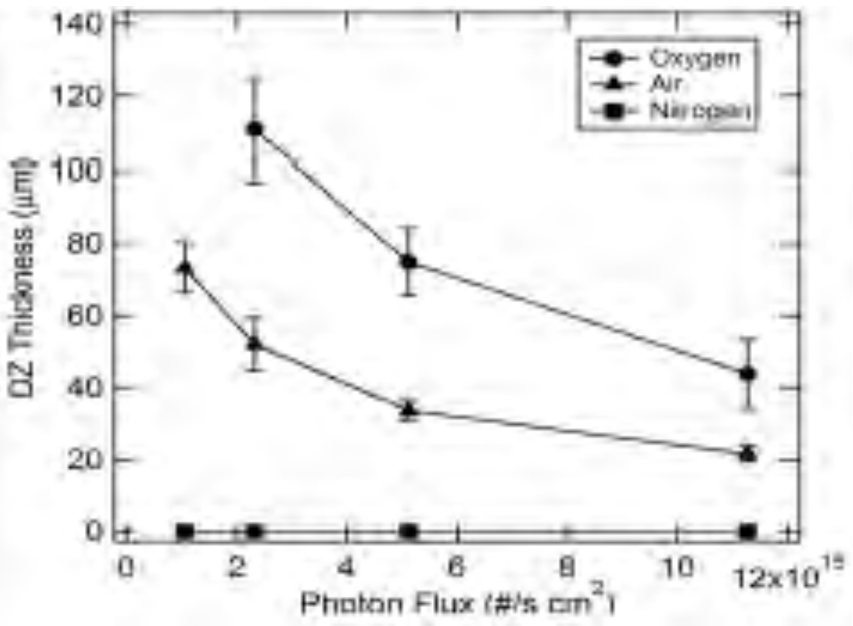
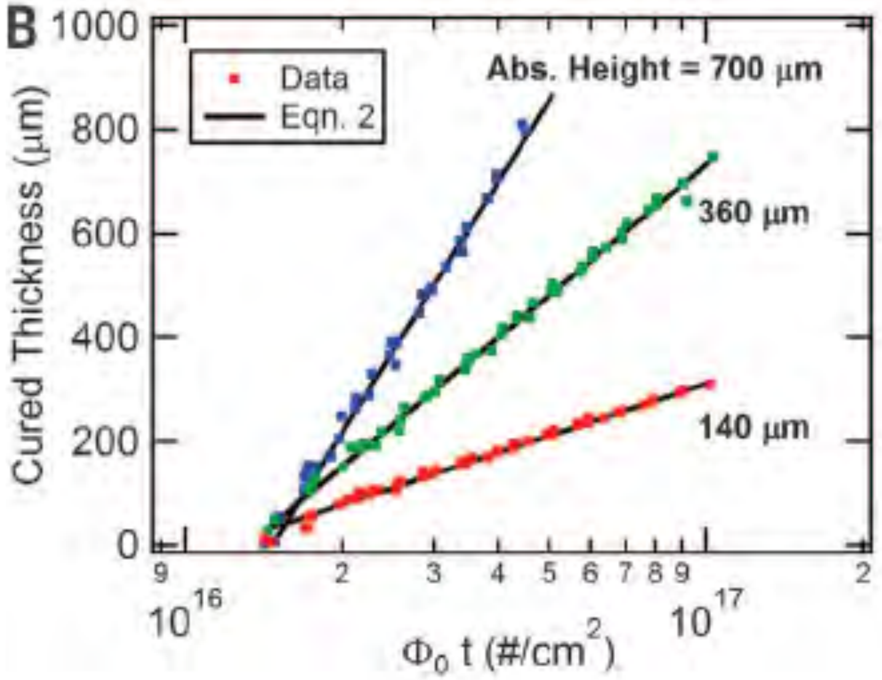




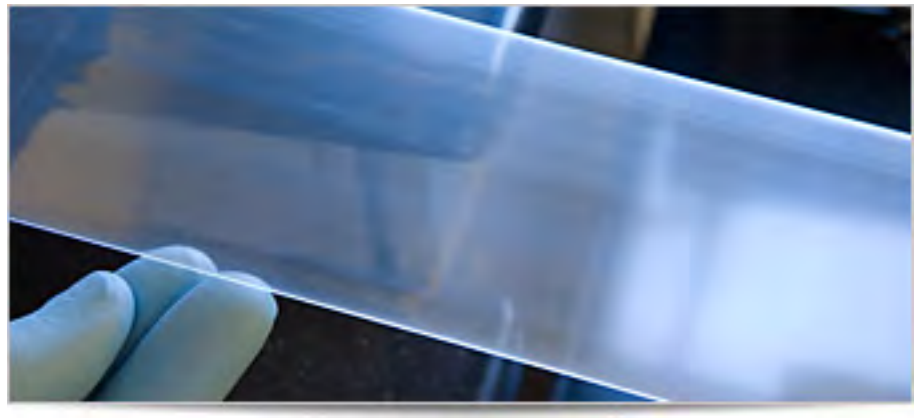


“Print Button”

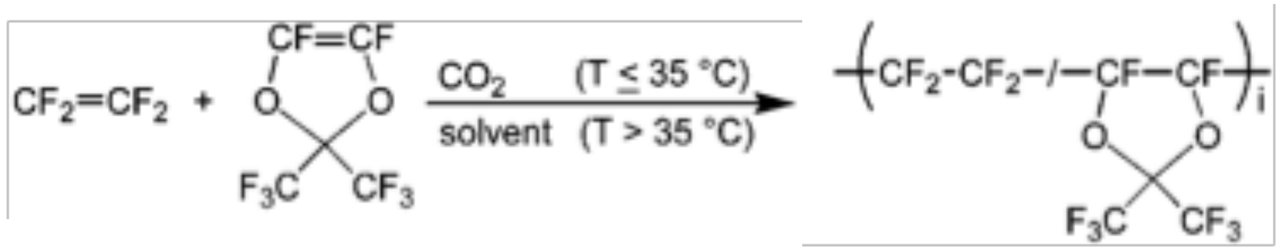
Key Features of the CLIP Window

Science **2015**, *347*(6228), 1349-1352

- Optically transparent at 385 nm
- Highly permeable to oxygen
- Chemically resistant to a wide range of organic liquids
- Thermally stable
- Photochemically stable
- Mechanically strong and durable
- Works well for small areas, not for areas > 1 cm^2 due to "drumming"



Polymerizations in Supercritical CO_2



Science **1992**, *257*, 945

Macromolecules **2003**, *36*, 7107

Advanced Rigid Window Technology

- Important aspects:
  - Able to handle significant forces over large areas, and extensible to multiple projectors
  - Maintain uniform temperature profile (dynamically) during complex builds (software controlled)
  - Operate at elevated temperatures
  - Able to vary oxygen flux
  - Exploit IoT for self-calibration
  - Pixel sizes over multiple orders of magnitude
  - Reliable and robust

Heated Rigid Window

- Can heat resins up to 65 °C
- Reduces viscosity of resins for better flow, allowing access to new higher viscosity resins
- Uniform heat distribution across the print for improved part accuracy
- Greater extent of polymerization conversion during printing resulting in improved mechanical properties

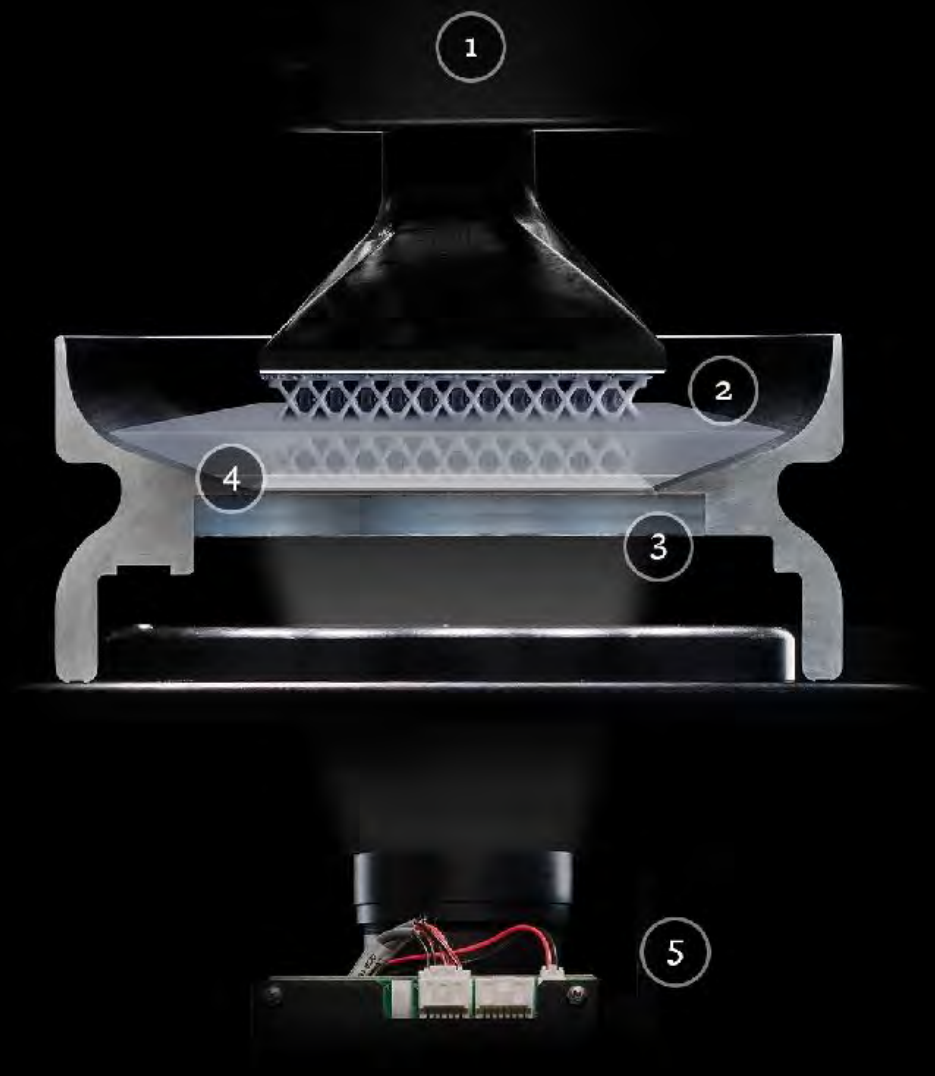
Components of CLIP

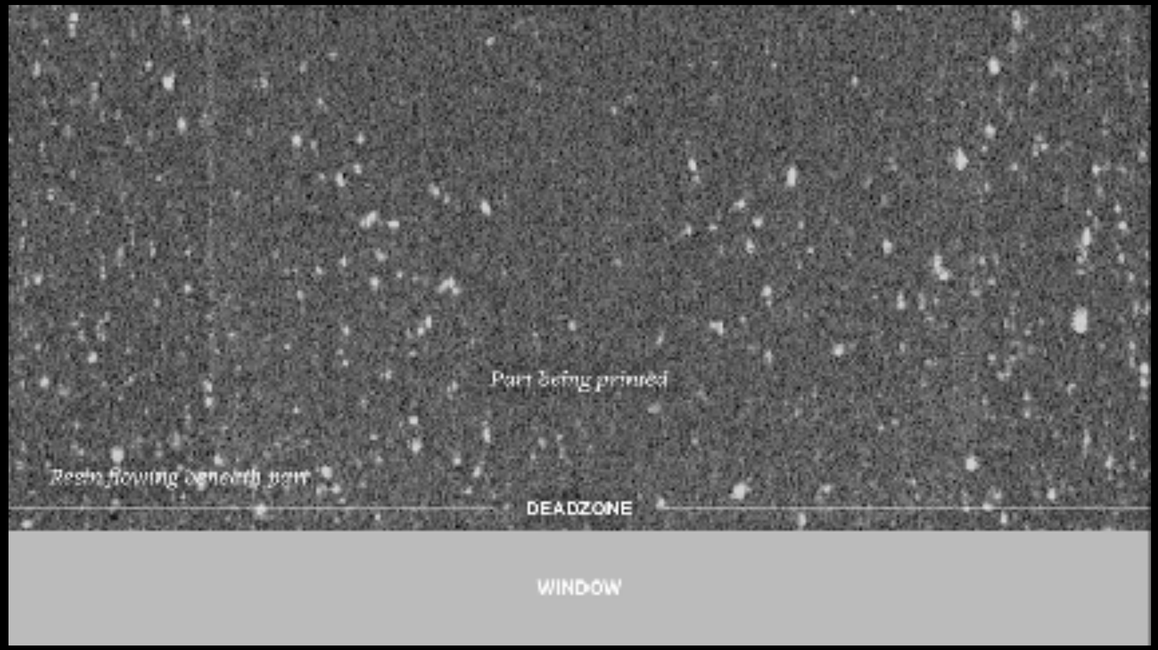
(Continuous Liquid Interface Production)

Speed - reactive resins

Gentle - green state

Digital - surface finish





Printing on Immiscible Liquids:
An Alternative Approach to a Solid Window?

(12) **United States Patent**
Robeson et al.

(10) **Patent No.:** **US 10,259,171 B2**
(45) **Date of Patent:** **Apr. 16, 2019**

(54) **CONTINUOUS THREE DIMENSIONAL FABRICATION FROM IMMISCIBLE LIQUIDS**

(71) Applicant: **Carbon, Inc.**, Redwood City, CA (US)

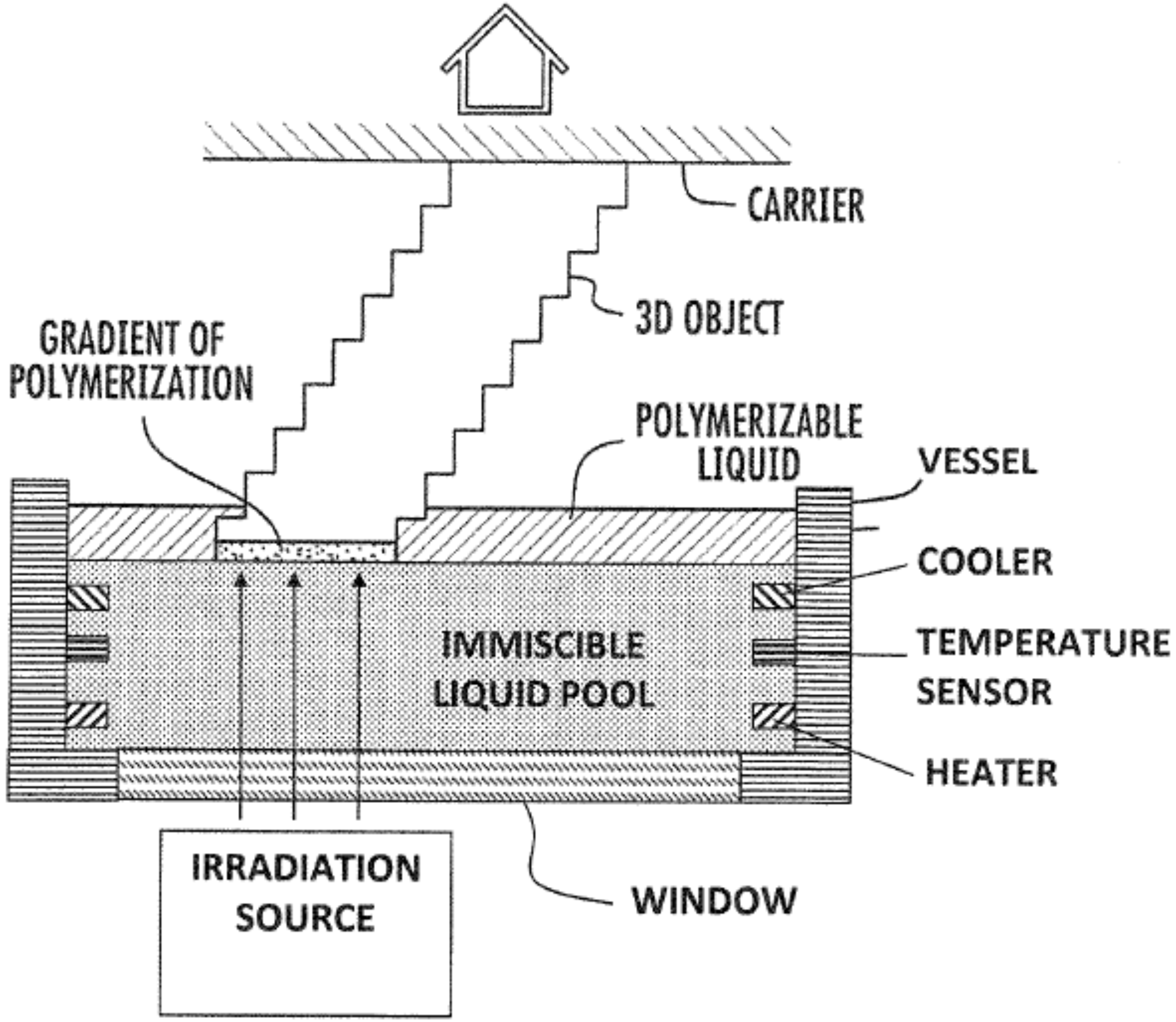
(72) Inventors: **Lloyd M. Robeson**, Macungie, PA (US); **Edward T. Samulski**, Chapel Hill, NC (US); **Alexander Ermoshkin**, Pittsboro, NC (US); **Joseph M. DeSimone**, Monte Sereno, CA (US)

(73) Assignee: **CARBON, INC.**, Redwood City, CA (US)

(60) Provisional application No. 61/984,099, filed on Apr. 25, 2014.

Nonaqueous Immiscible Liquids.

Although aqueous liquids are preferred for the immiscible liquid, in some embodiments preferred, nonaqueous liquid layers may be preferable for specific reaction systems. Examples include higher density hydrocarbon liquids such as ethylene glycol, diethylene glycol, triethylene glycol, glycerol, formamide, fluorocarbons and perfluorcarbon liquids such as Kytox (duPont) or Fomblin perfluorinated polyether oil. Low toxicity chlorinated aliphatic hydrocar-

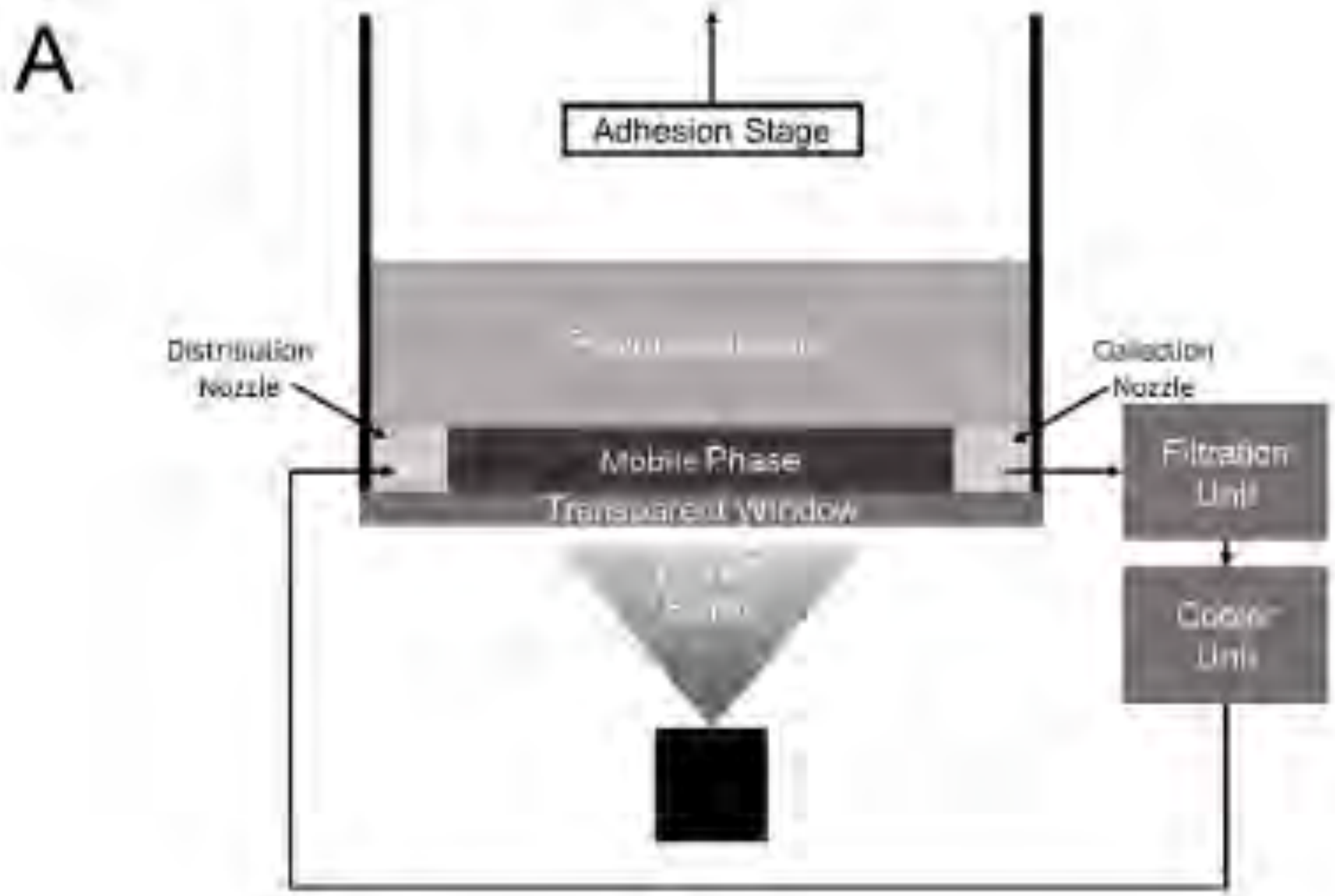


While in the illustrated embodiments the pool is shown as a static or stationary pool, in other embodiments circulation of immiscible liquid may be provided through the pool, for example to cool the pool, or refresh oxygen content therein (e.g., of fluorinated fluids).

Rapid, large-volume, thermally controlled 3D printing using a mobile liquid interface

David A. Walker[1,2]*, James L. Hedrick[2,3]*, Chad A. Mirkin[1,2,3]†

Walker *et al.*, *Science* **366**, 360–364 (2019)   18 October 2019



The printer operates on the principle of a UV-curable resin floating on a bed of flowing immiscible fluorinated oil to minimize interfacial adhesion at the build region.

We report a dead layer–free approach to rapid SLA printing, HARP (high-area rapid printing),

Fluorinated oils (perfluoropolyether copolymers, such as Solvay Fomblin Y or Chemours Krytox GPL) were chosen for their omniphobic properties and higher densities relative to that of common SLA resins.

Moreover, the delivery of gaseous oxygen, a thermal insulator, through the print bed to create a dead layer limits one to peripheral cooling options that cannot rapidly dissipate the heat being generated.

3D PRINTING

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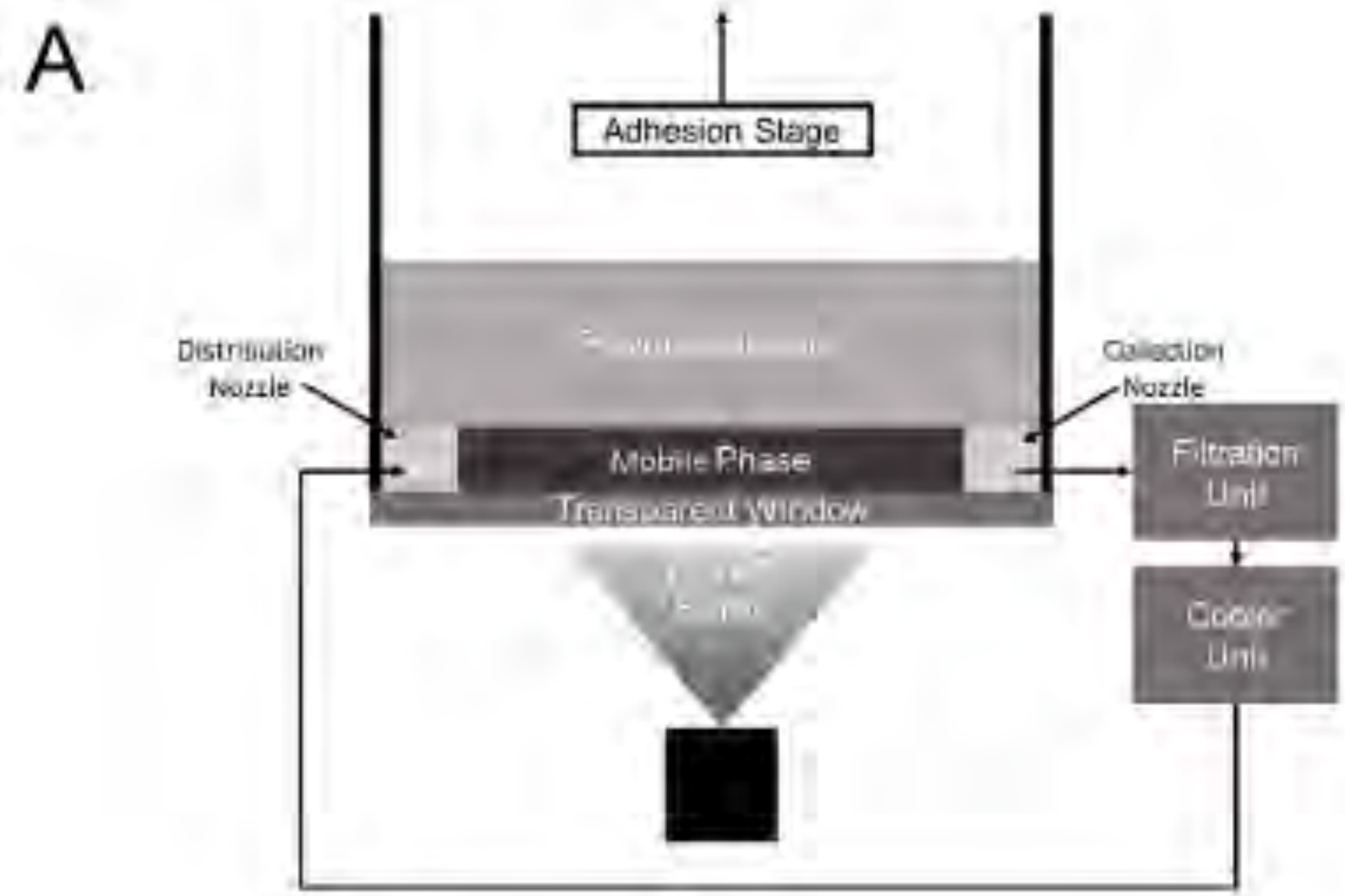
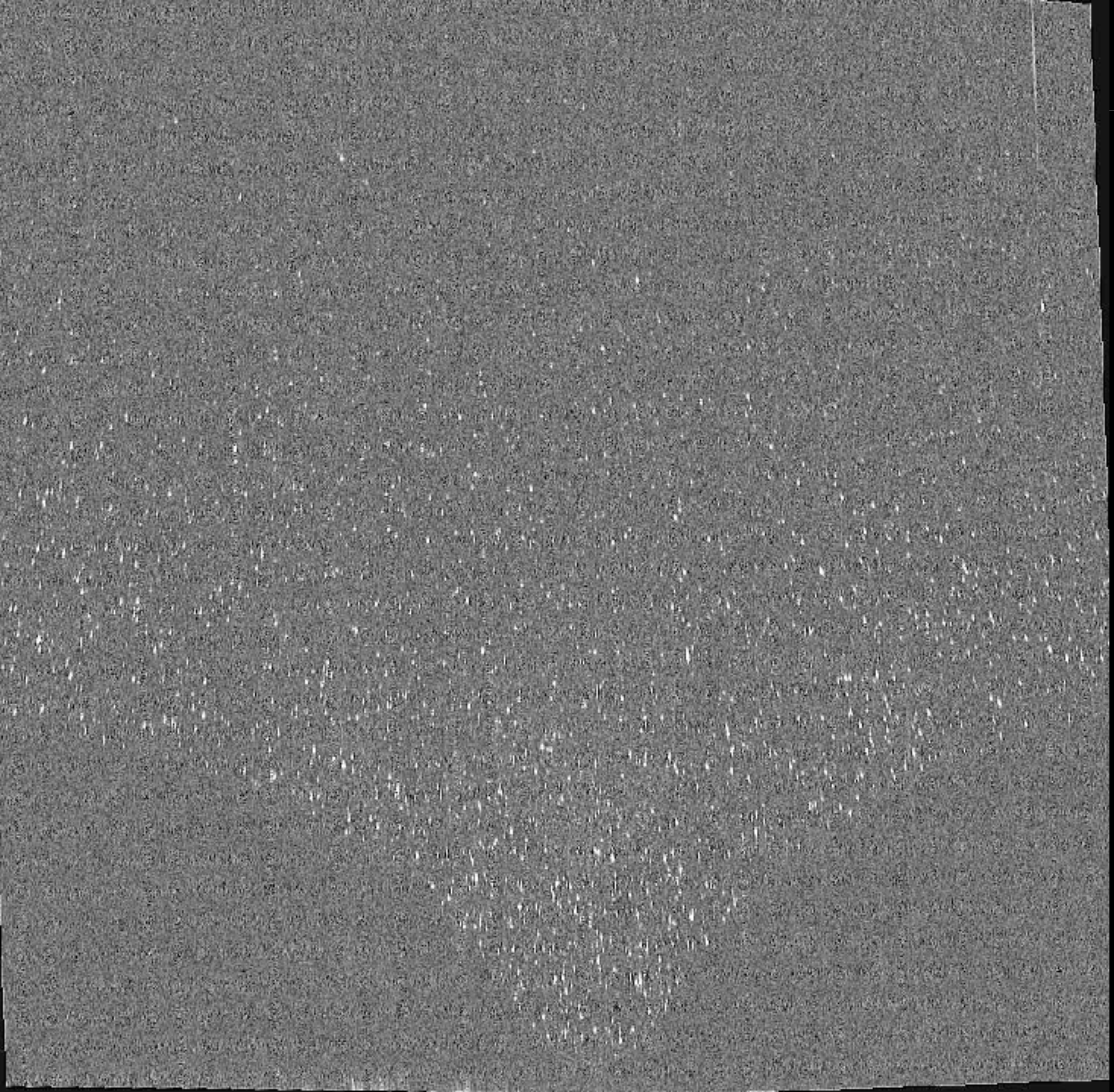
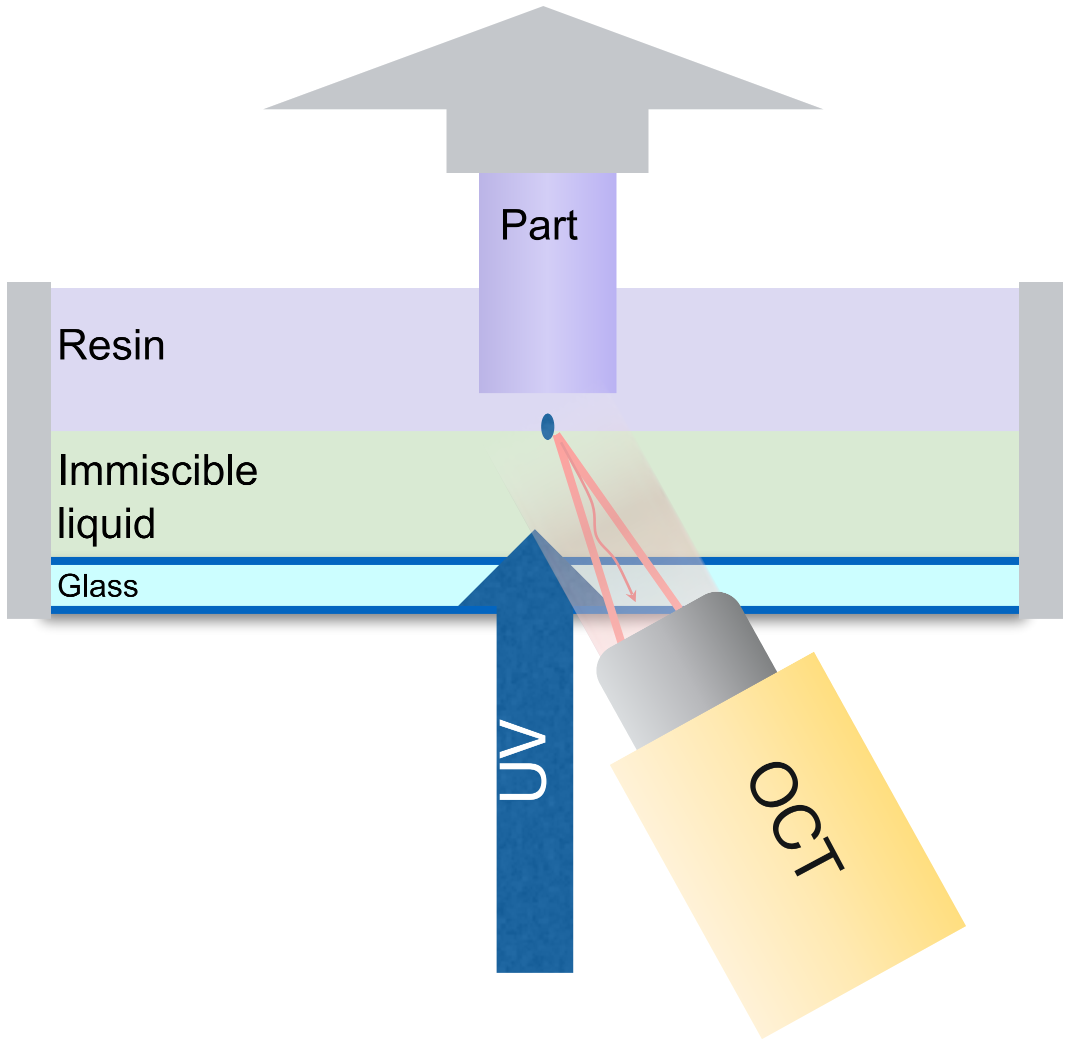




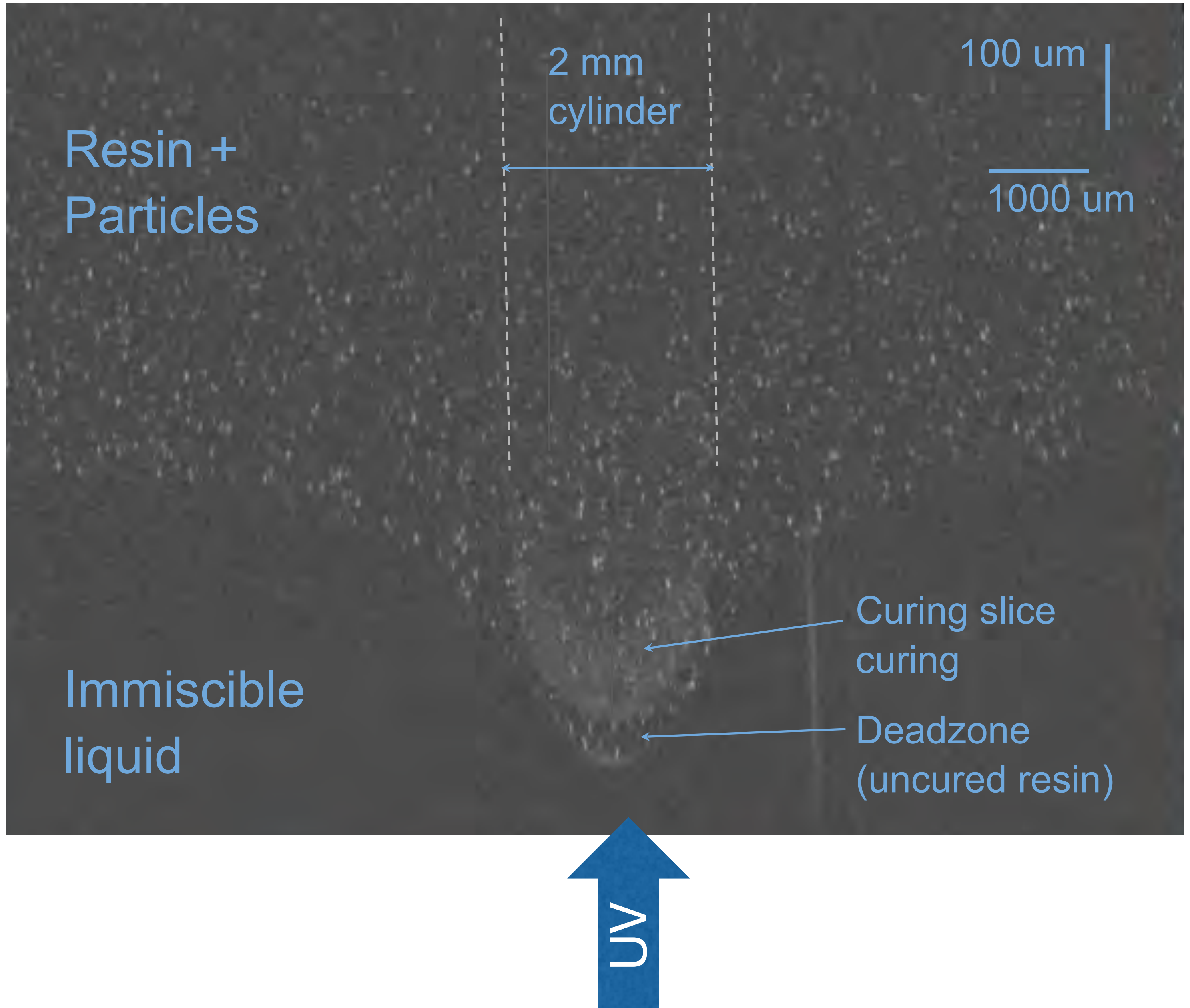
- Printing on immiscible fluorocarbons under ambient conditions clearly shows the formation of a dead zone caused by dissolved oxygen in the fluorinated phase
- The dead zone plays a critical role in the renewal of the liquid resin at the build surface

Optical coherence tomography for in-situ imaging of print dynamics

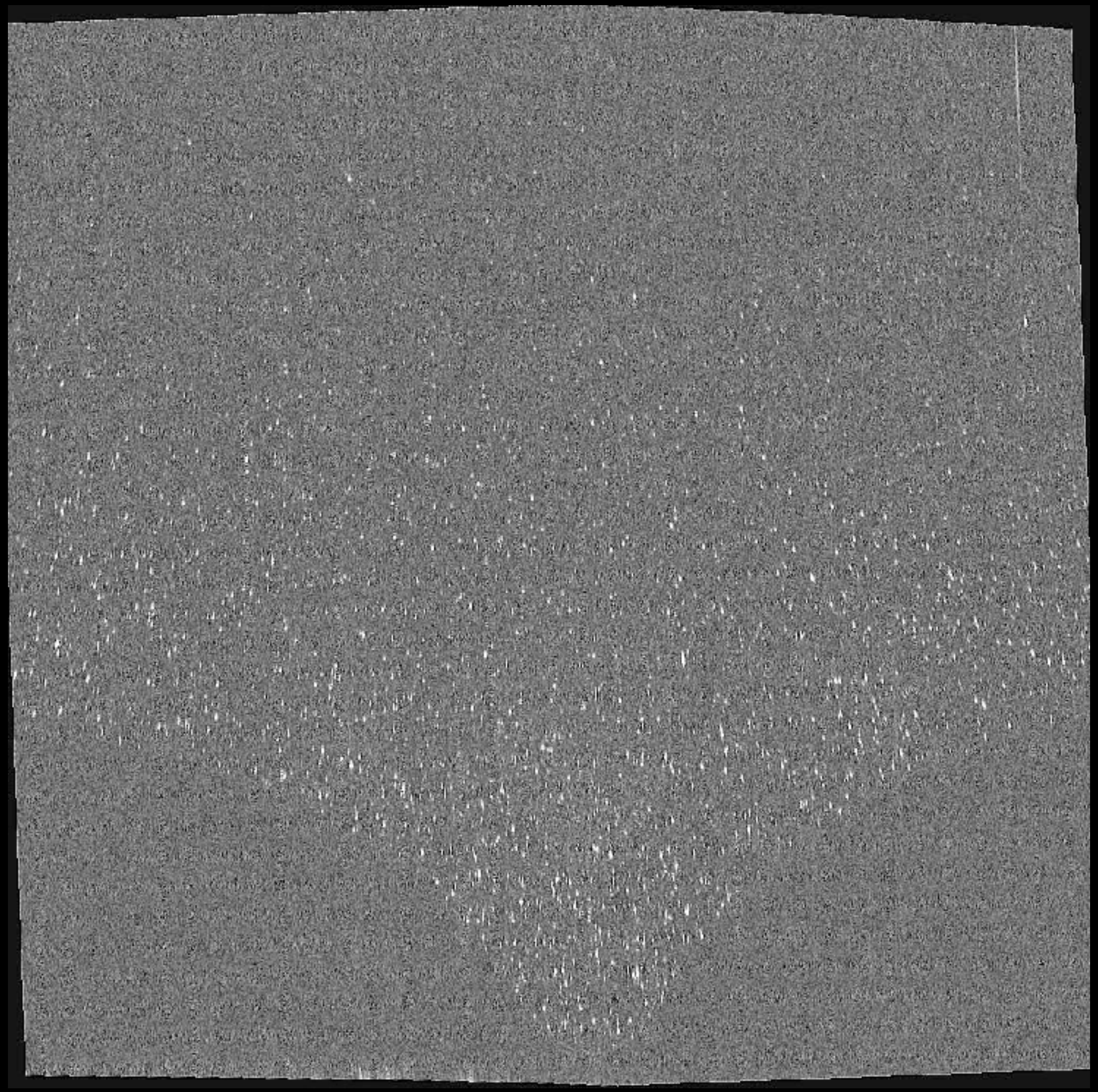
- Optical backscattering images, analogous to ultrasound.
- Real time imaging of internal 2D slices through part with ~4 um z-resolution.



Example cross-section image of slice through middle of part



Printing on Immiscible Fluorocarbons



Printing on Rigid Fluorocarbon

Rapid, large-volume, thermally controlled 3D printing using a mobile liquid interface

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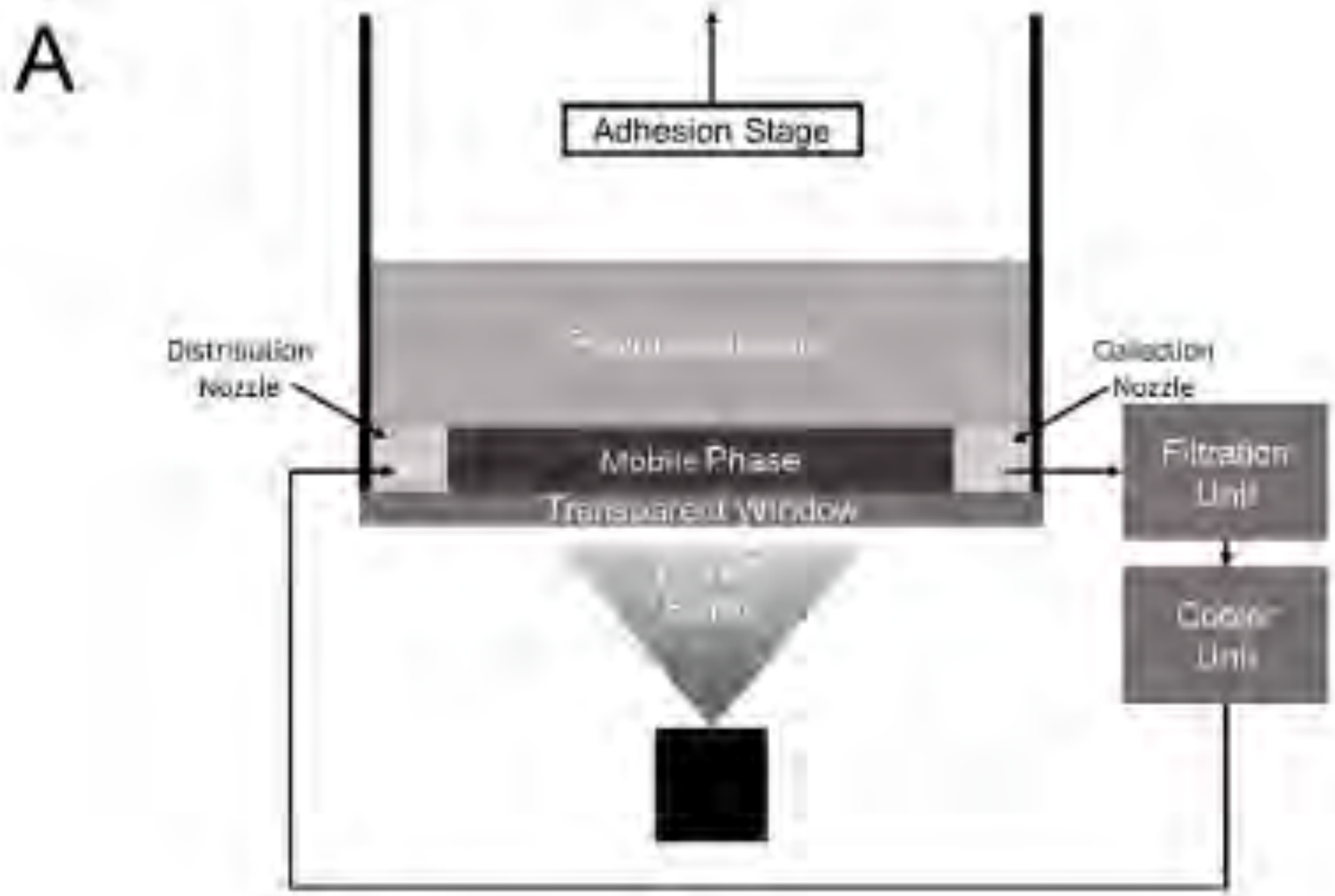
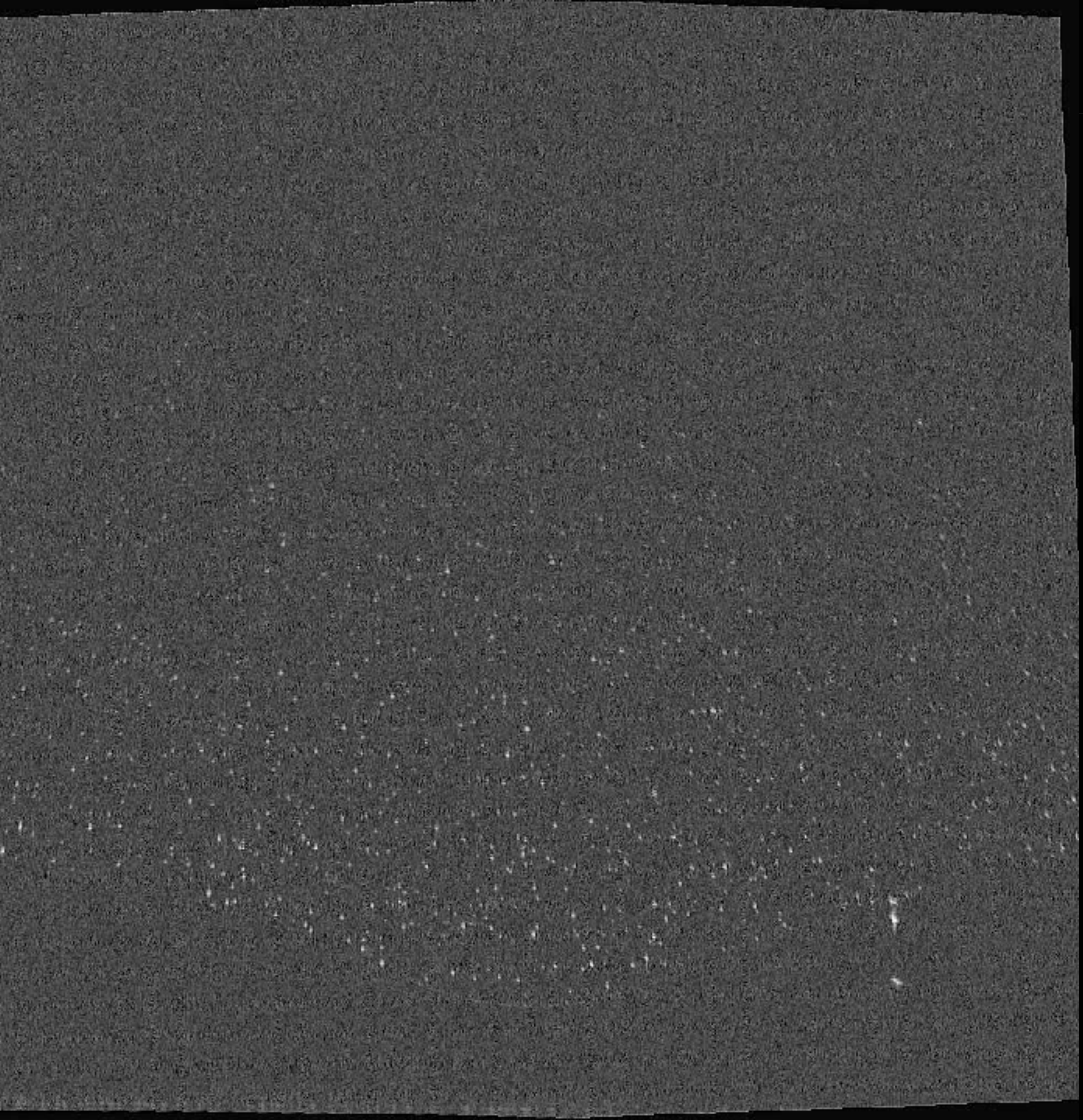
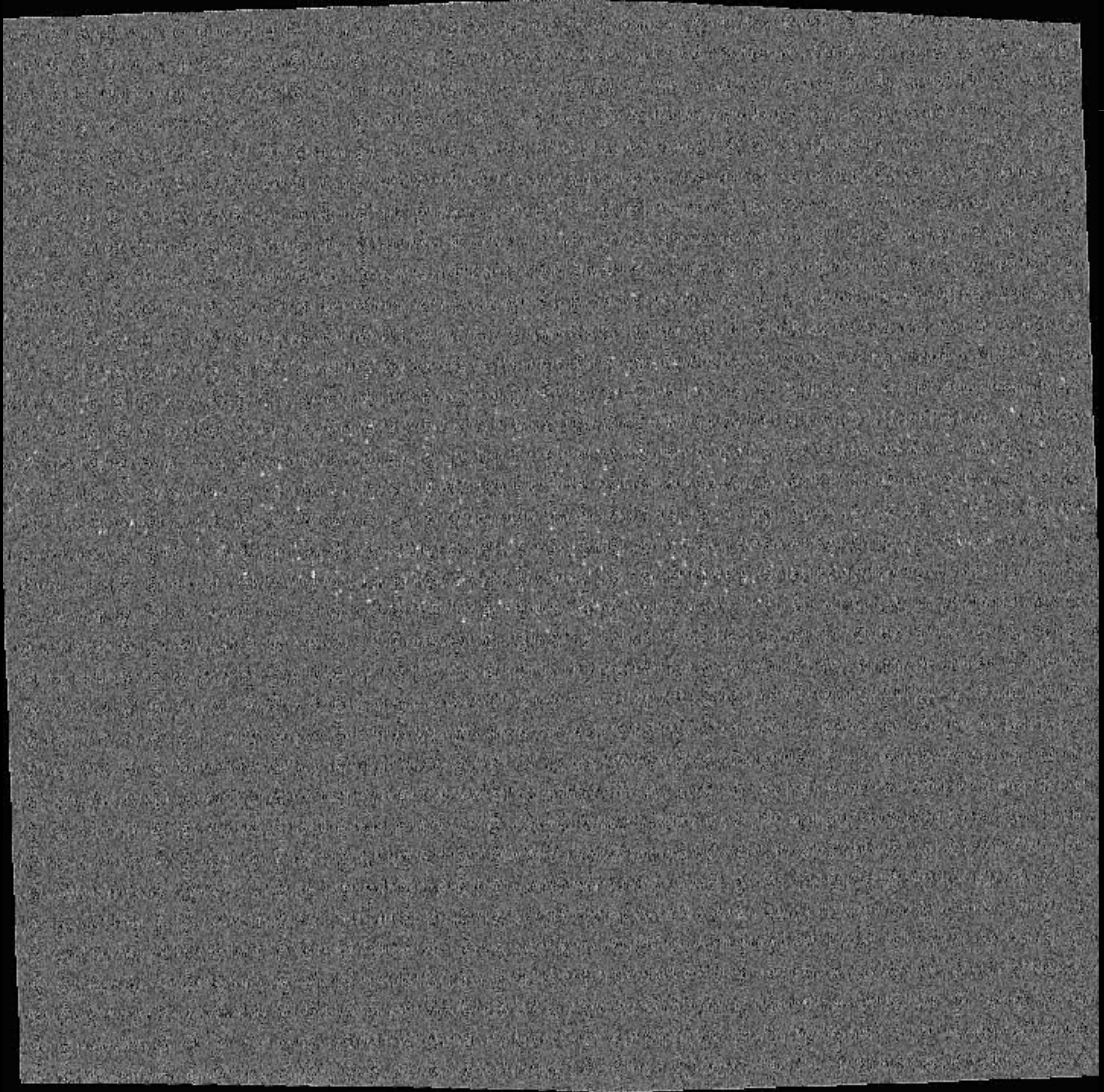
Walker *et al.*, *Science* **366**, 360–364 (2019) 18 October 2019



HARP-printed parts have a surface ridging that depends on the minimal wall thickness of the object being printed; thinner part sections result in faster resin replenishment rates and consequently yield a smoother surface.



- Printing on immiscible fluorocarbons under flow
- Fc770 (viscosity of 1cP, density = 1.8 g/cc)
- Flow rate 3 mm/s
- Very little difference in the printing dynamics between with and without flow
  - Only difference is that with flow, there is drag on the resin from right to left…



- Printing on immiscible fluorocarbons that have been de-gassed eliminates the dead zone

- Without a dead zone, significant defects in the parts are observed

- These defects are identical to the defects one sees when printing on glycerin and aqueous solutions (negligible oxygen sources)

3D PRINTING

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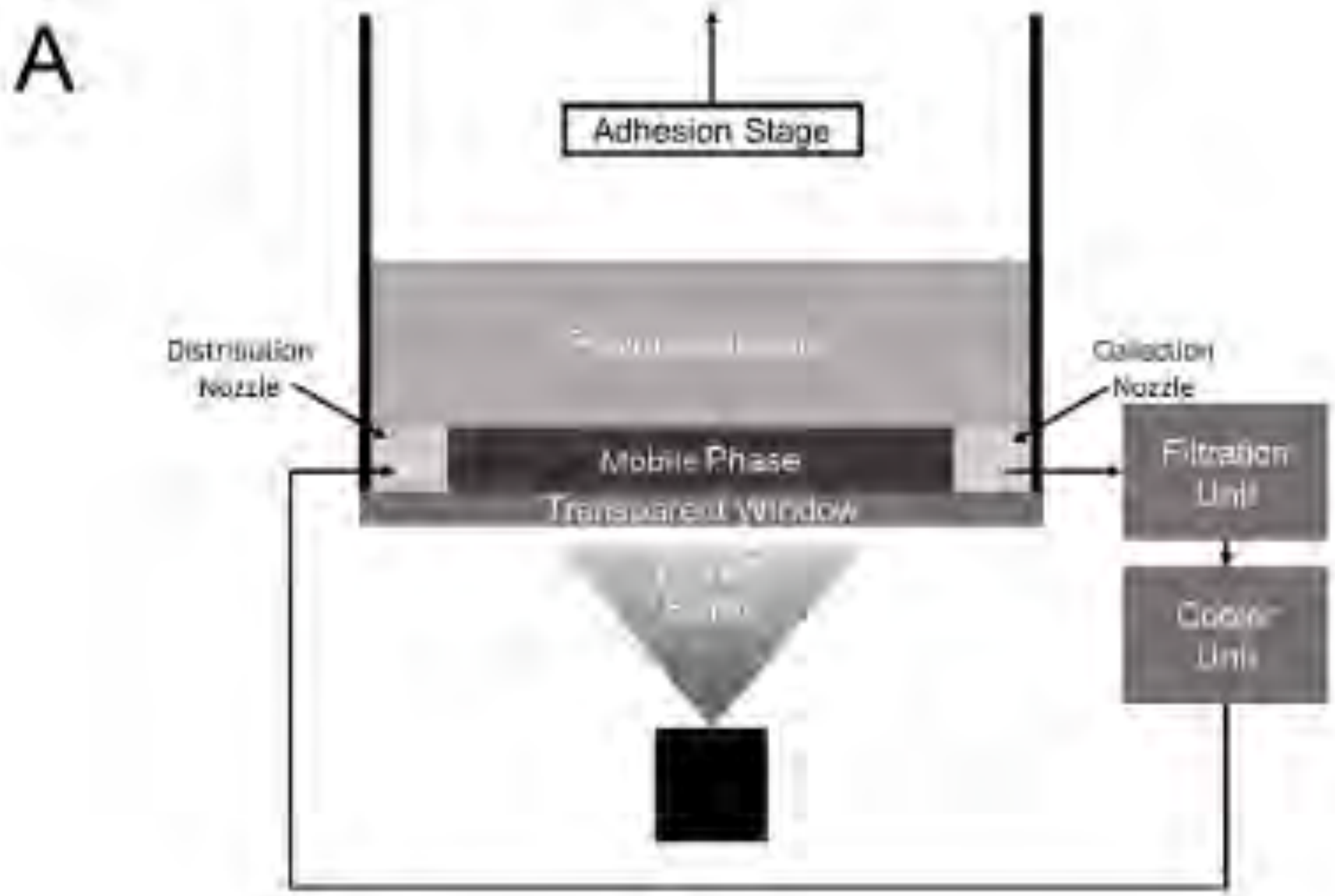
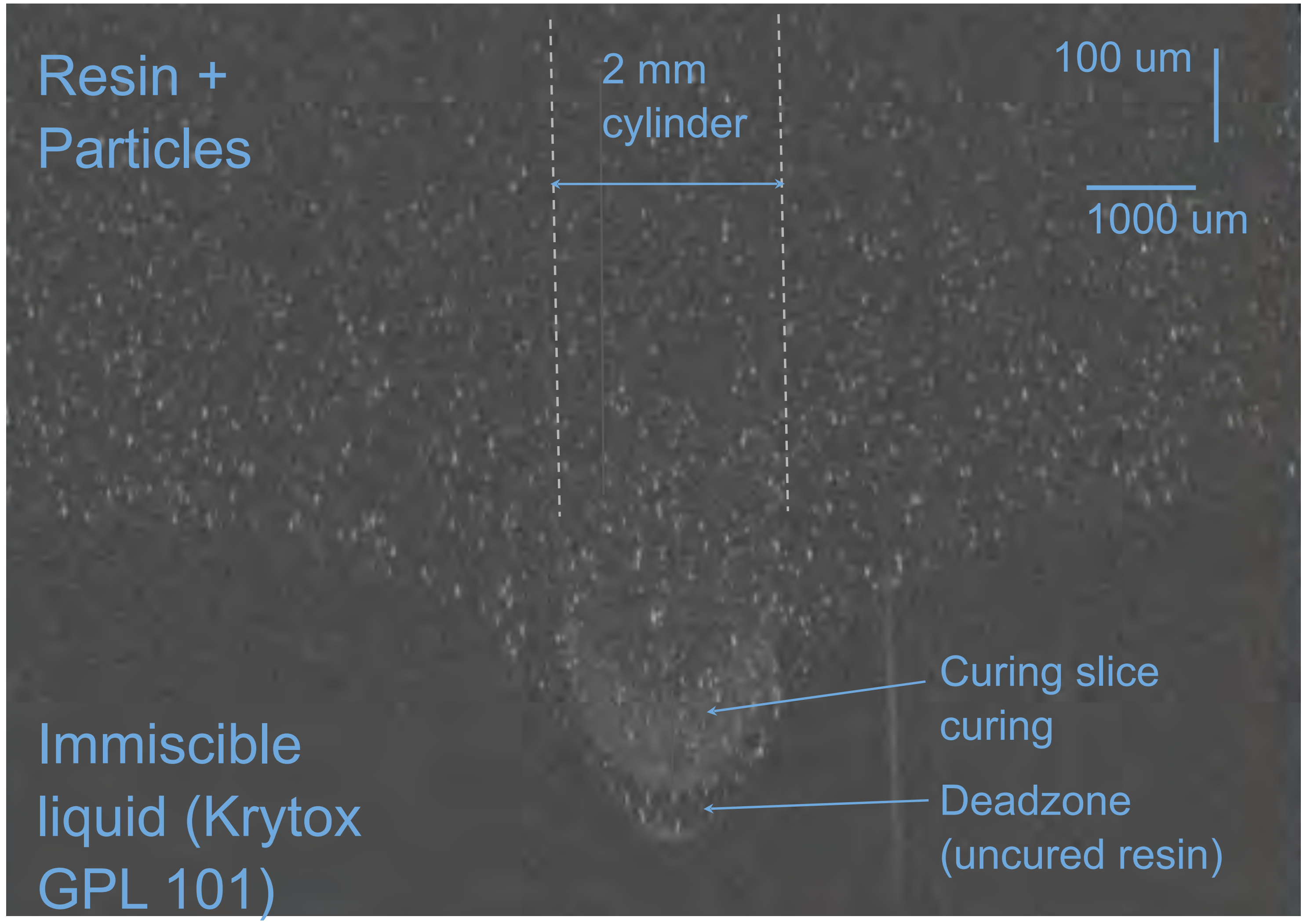


Fig. S7

Example Part Printed on Glycol. ASTM D638 Type I dog bones printed on (A) fluorinated oil, and (B) glycerin. As can be seen, parts printed on glycerin result in 'flaky' and hollow parts owing to the subpar de-wetting behavior of the immiscible phase. Parts were printed with a hard urethane acrylate resin, a monochromatic UV source (100 µm optical resolution), and a TPO photoinitiator. Scalebar is 1 cm.

Residual Oxygen in immiscible liquid creates a deadzone

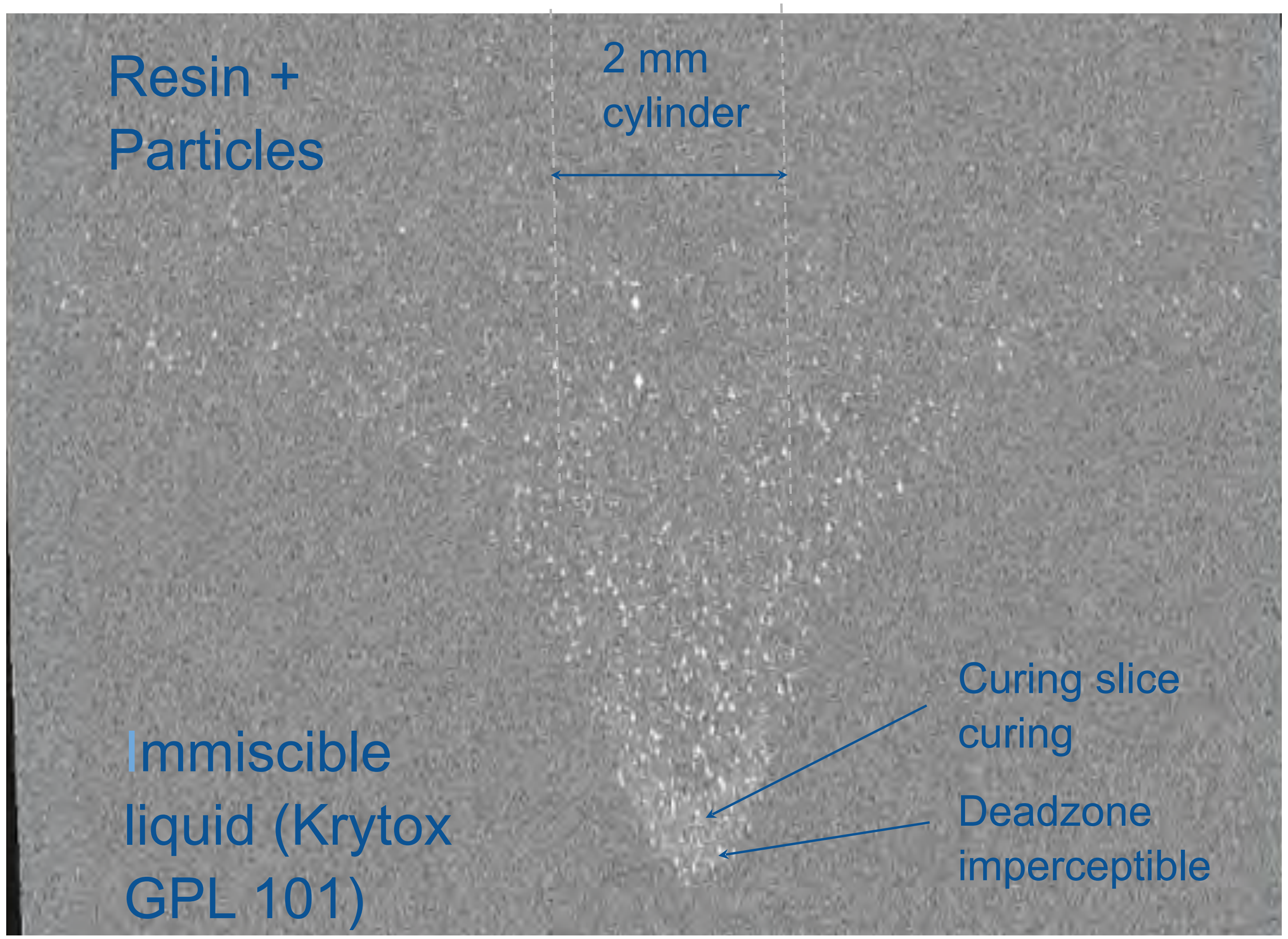
Unprocessed GLP101
→ Significant deadzone



GPL 101 viscosity ~17 cSt
GPL density = 1.9 g/cc

Resin Ec = 23 mJ/cm2
Resin cure depth, Dp = 1500 um
I = 4.5 mW/cm2

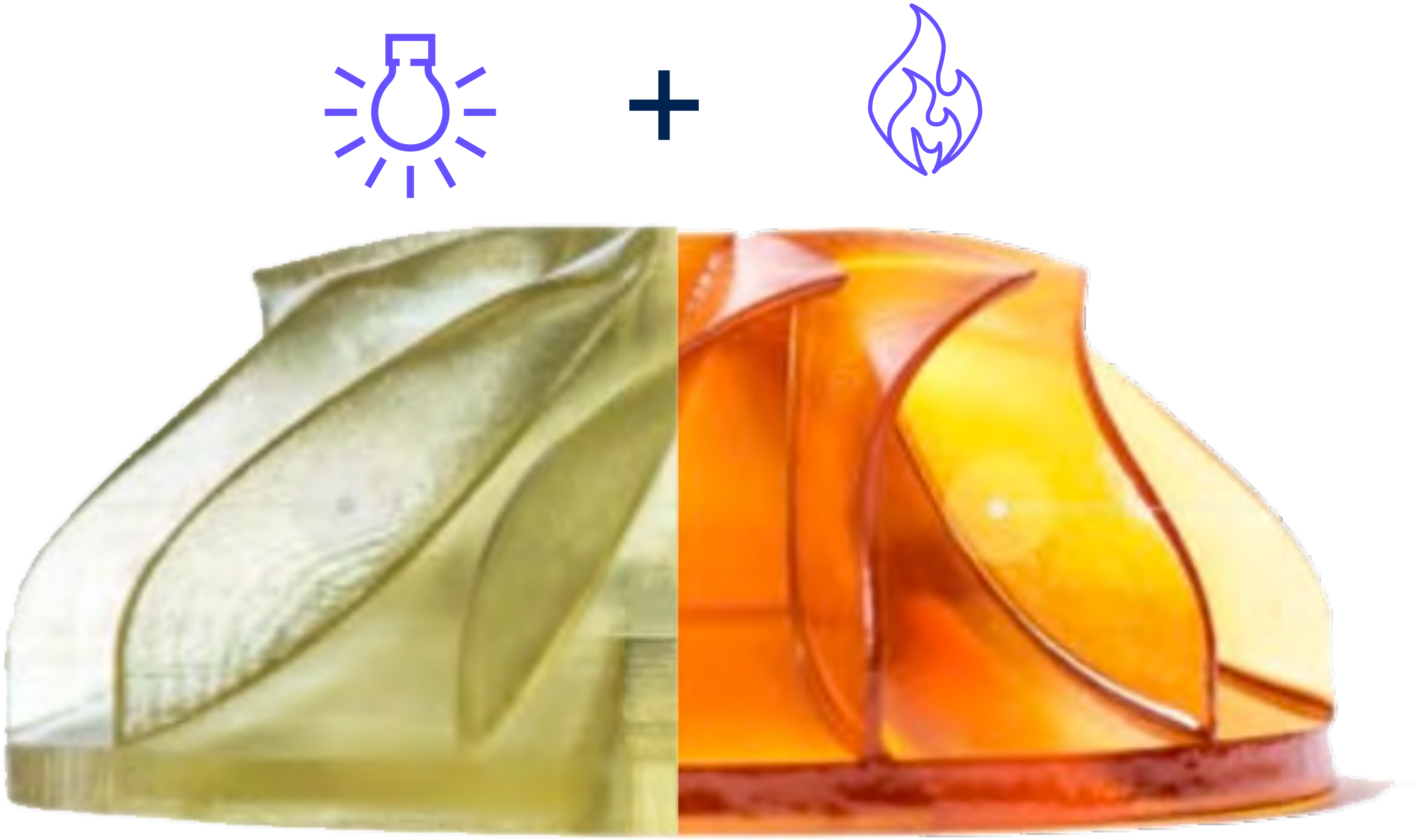
Deoxygenated Krytox GPL101
→ Imperceptible deadzone



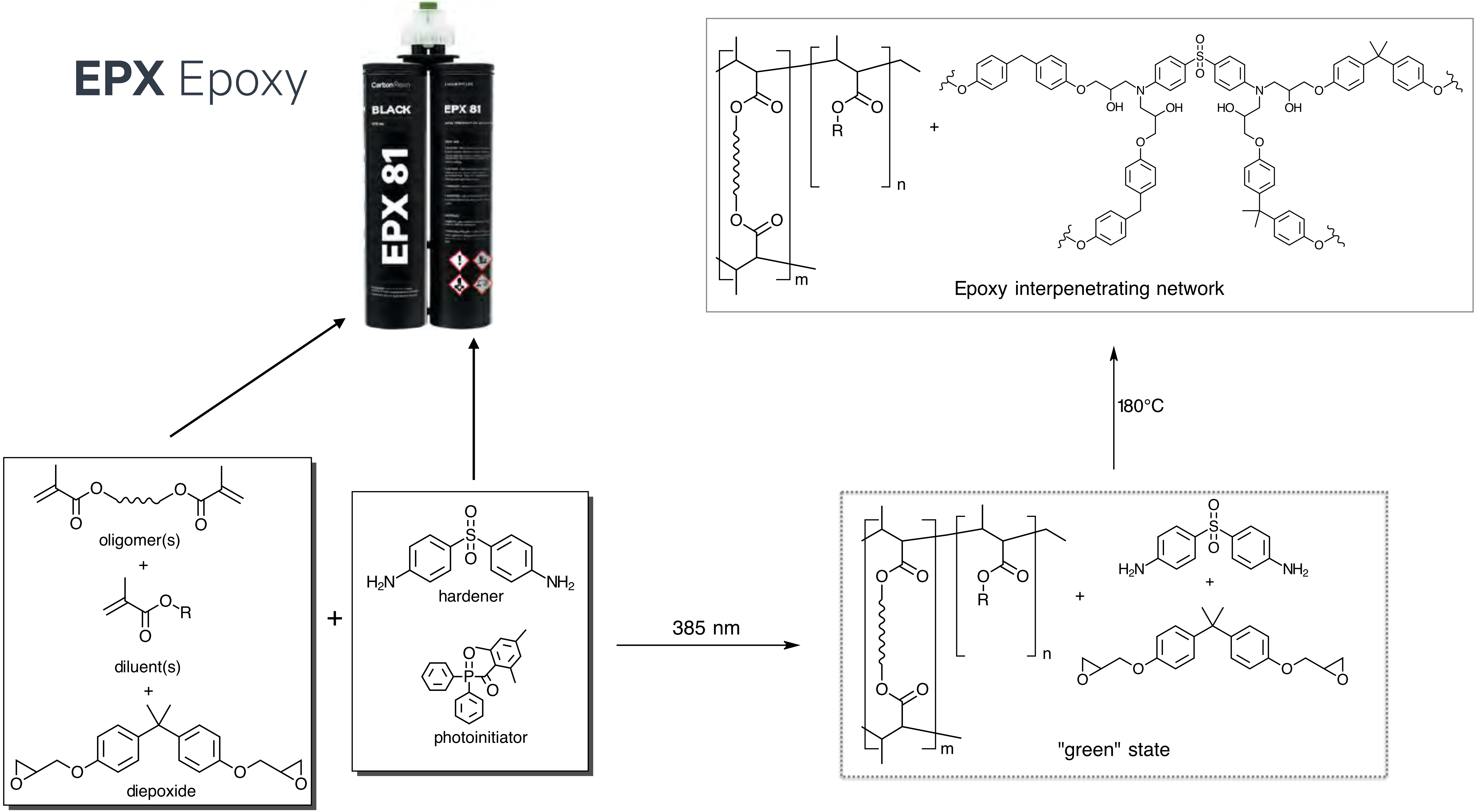
Printing on Immiscible Liquids: An Alternative Approach to a Solid Window?

- With a dead zone, it works but it is not as attractive as a solid window
  - Entrainment of the immiscible fluid in the parts: messy!
  - Some partitioning of small molecule components into the immiscible phase
  - Surface finish issues (just like our thin film flexible window…)
- Without a dead zone (de-gassing the fluorocarbon), it doesn't work well
- Mirkin *et. al.* in ***Science*** *366*, 360-364 (2019):
  - Neglected the role of oxygen in "HARP" *AND* oxygen is playing *THE* critical role
  - Slip *per se* doesn't seem to offer anything….

Dual cure resins



EPX Epoxy



Carbon Resin
BLACK
EPX 81
EPX 81
Epoxy interpenetrating network
180°C
oligomer(s)
+
diluent(s)
+
diepoxide
+
hardener
photoinitiator
385 nm
"green" state

EPX Epoxy

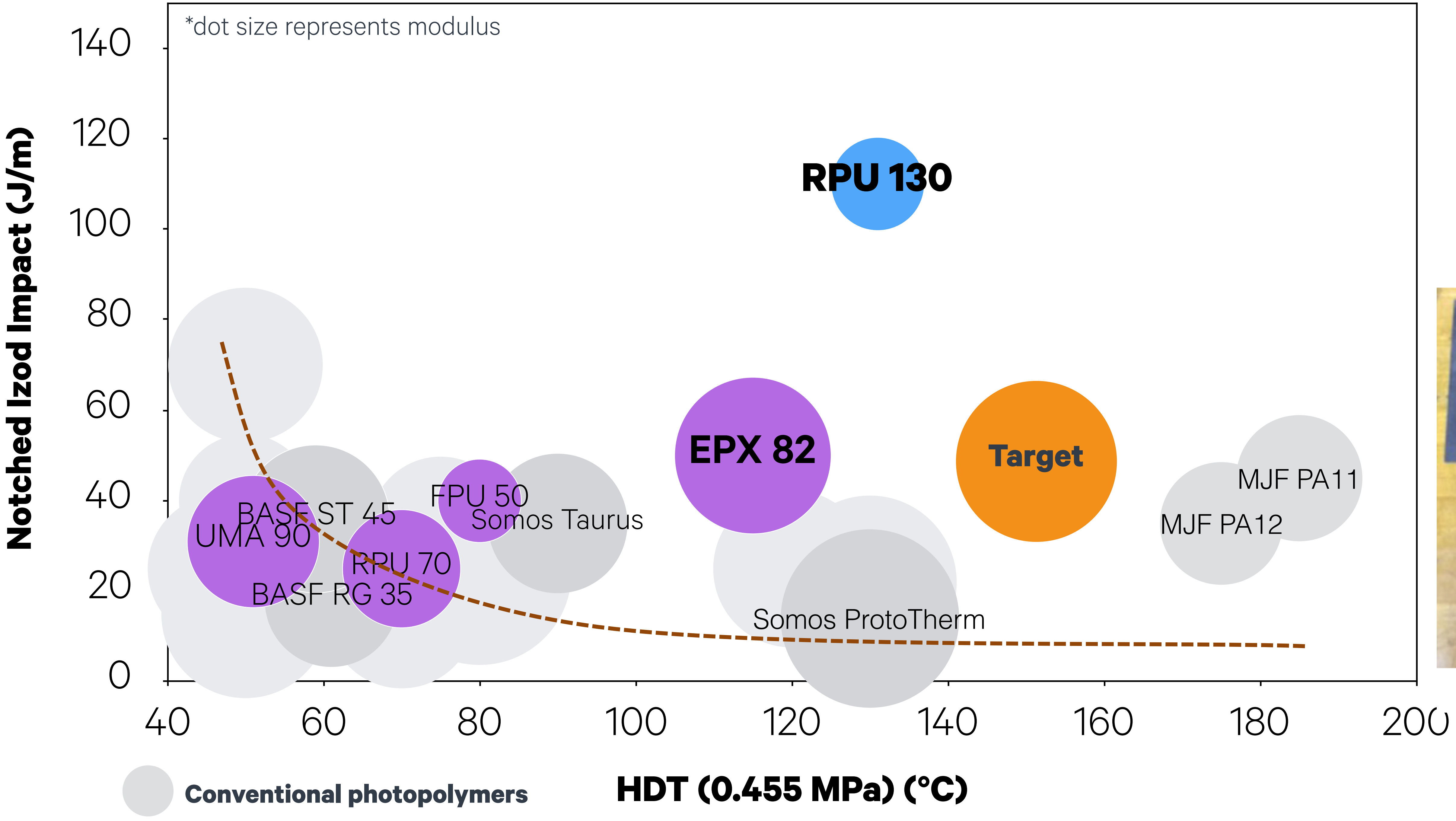
EPX is our most accurate high-strength engineering material. It has a heat deflection temperature of 125 °C, making it useful in a variety of automotive, industrial, and consumer applications.

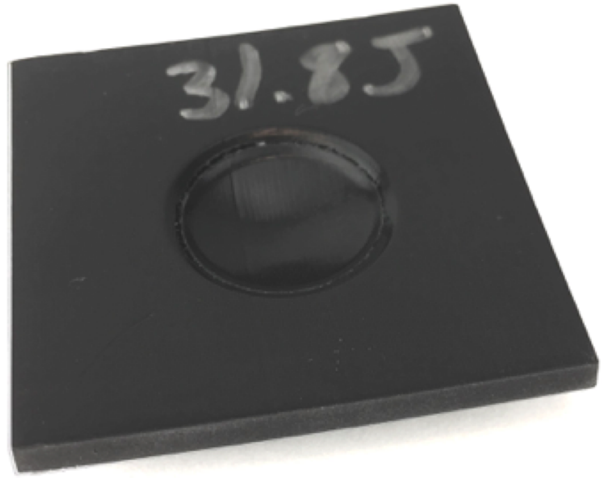
ULTIMATE TENSILE STRENGTH	88 ± 3 MPa
ELONGATION AT BREAK	5.2 ± 0.7%
YOUNG'S MODULUS	3140 ± 105 MPa
IMPACT STRENGTH (NOTCHED)	50 ± 5 J/m

In development: Flame-resistant EPX

- Passes UL94 V0 at 1.5 mm thickness
- Out for qualification per FAR 23.853 and 25.853 12 second burn

Engineering Polymers: Dual-cure Programmable Resins

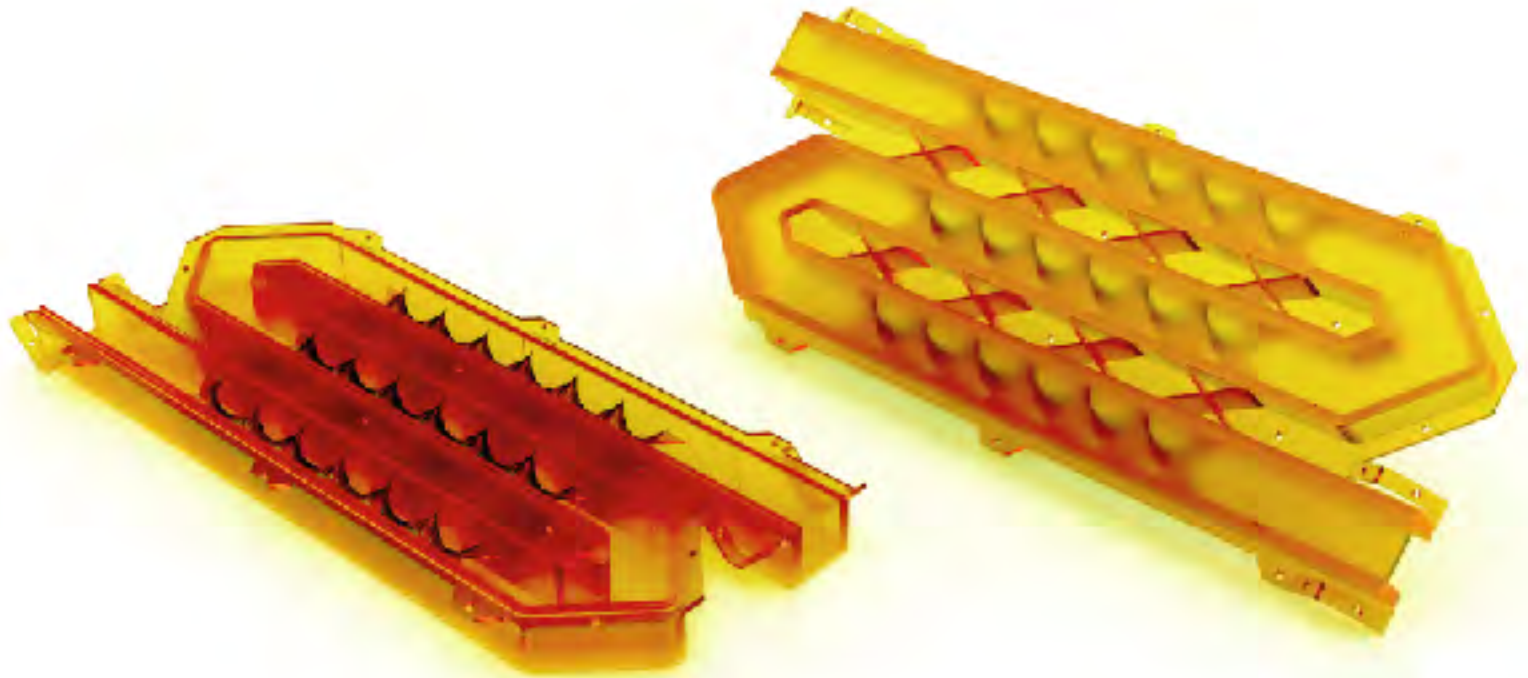




RPU 130 (ductile at 30J)

HP MJF PA12 (fail at 10J)

Heat Exchangers and Fluidics



Resin Store

2016–2018 RESINS
General use and early adopter production

RPU 70
Nozzles

EPU 41
Midsoles

CE 221
Fluidics

SIL 30
Padding

UMA 90
Speed

EPX 82
Automotive

EPU 40
Foam replacements

MPU 100
Medical

FPU 50
Enclosures

2019+ RESINS
Validated production focus

DENTAL MODELS

SURGICAL GUIDES

AUTOMOTIVE II

DENTURES

BIO-ABSORBABLE

AEROSPACE

MEDICAL

RECYCLE-ABLE

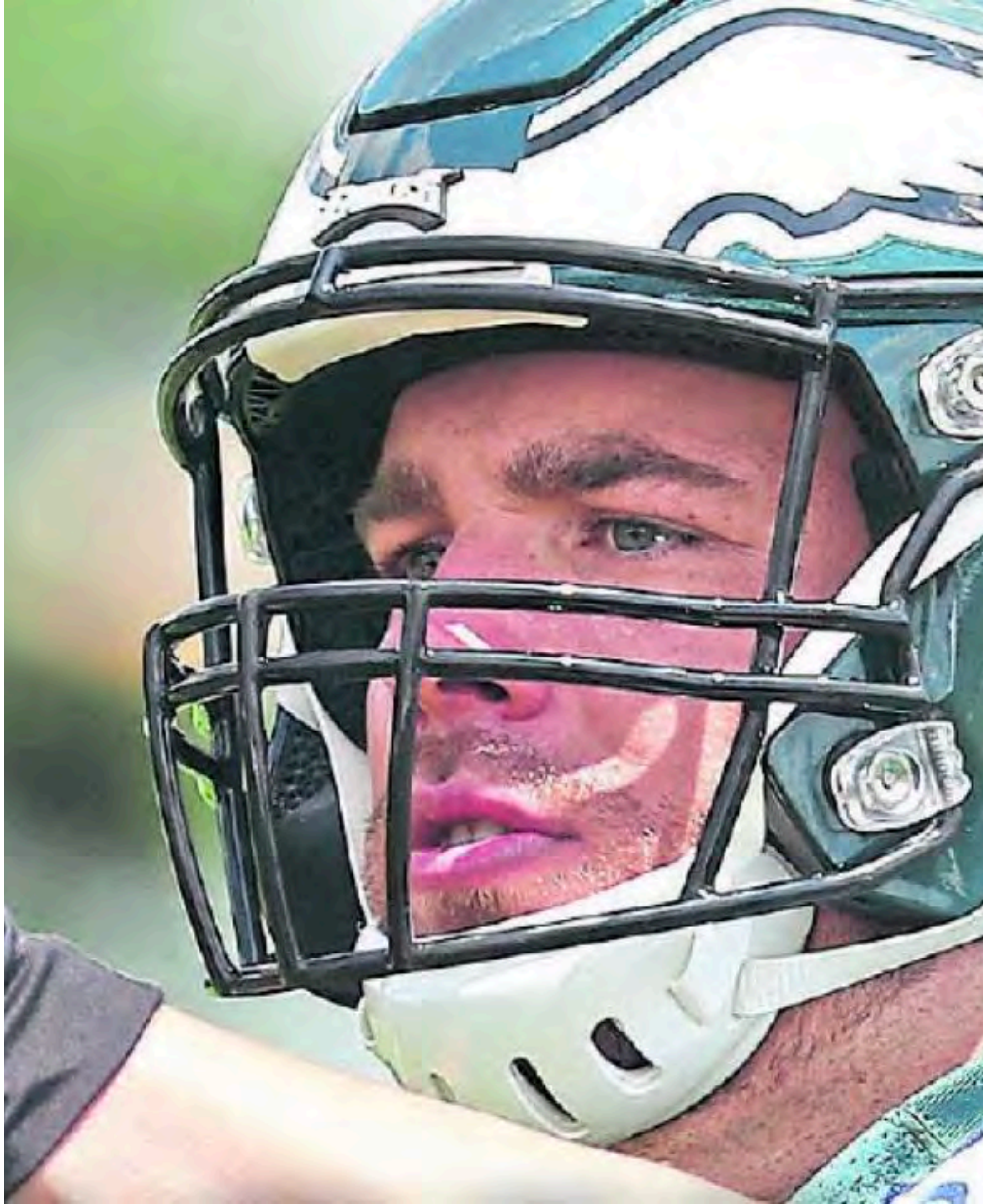
Making what the world needs

Challenge what's acceptable.
Create extraordinary.

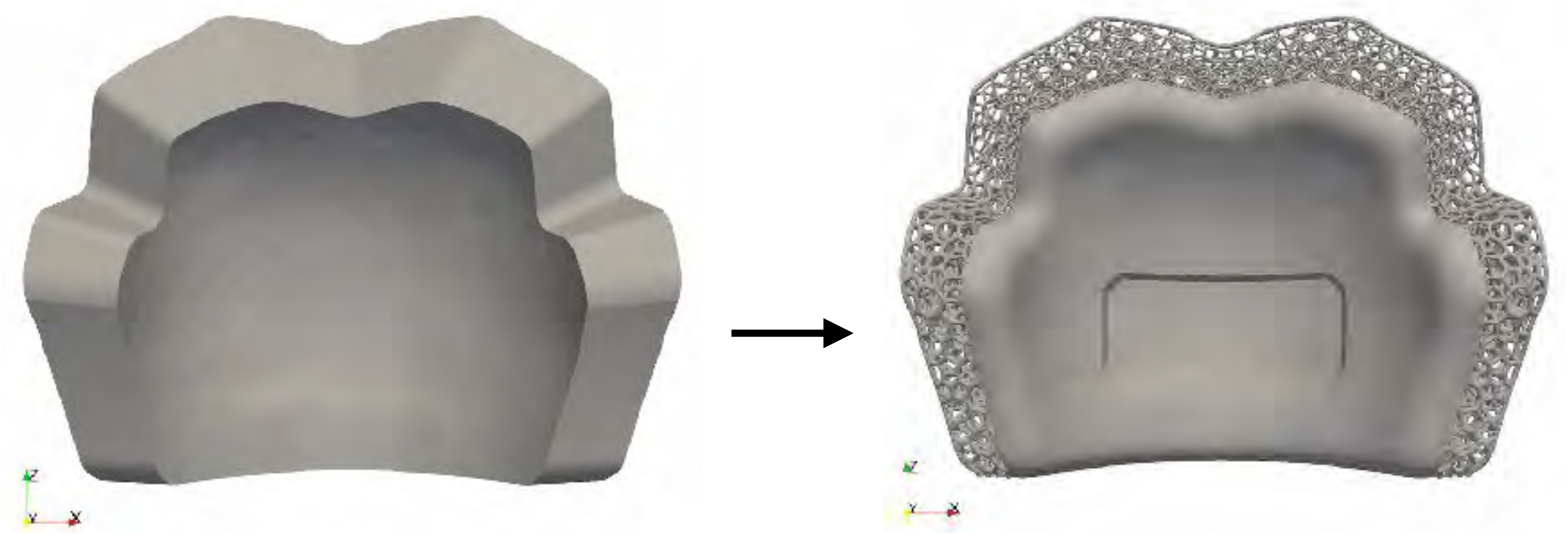
Head Protection


PATRIOTS


RAVENS

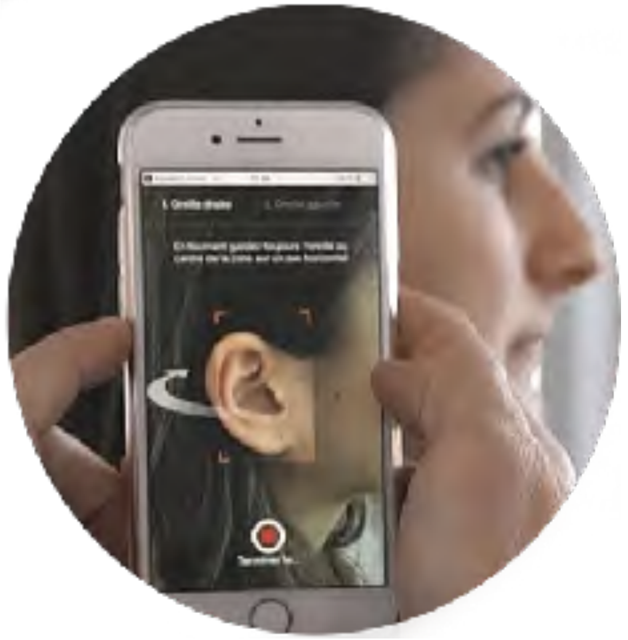


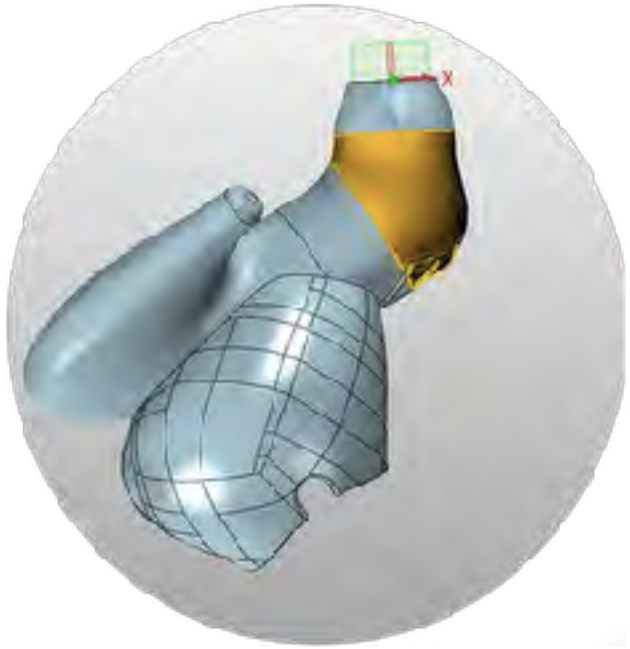
Customized Manufacturing : Digital Pipeline



- **Input:** provided by the customer for each player — specific CAD.
- **Automated Pipeline:** Creates a smooth CAD on subset of surface, generates a surface skin, builds surface parameterization to create recesses (applying textures), populate the performance related lattices, and also performs quality control checks for each part before it is sent to the printer.
  - Simple enough tool that it can be used by **manufacturing technicians (700+ helmets)**
  - **Eventually completely automatic —** no human intervention needed in the pipeline.

MyFit Solutions X Erpro





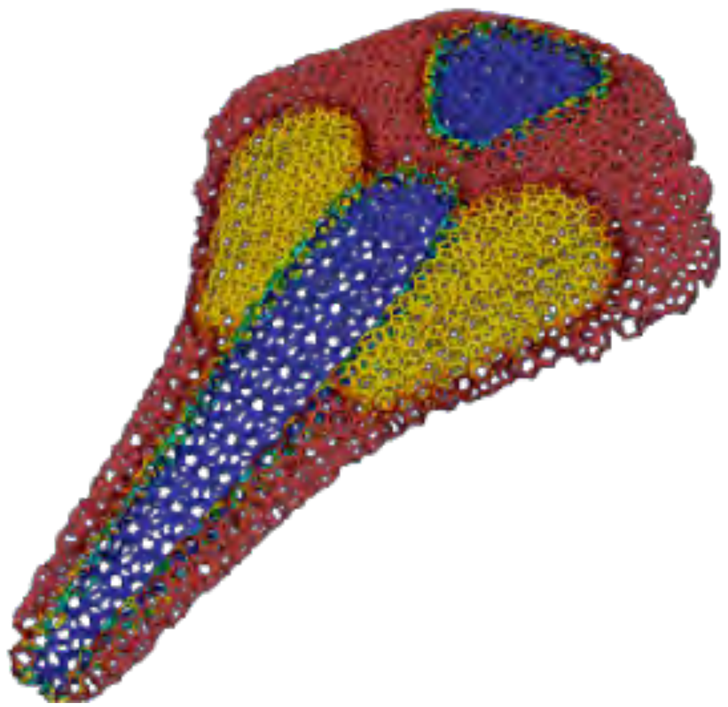
Customized In-Ear Buds:

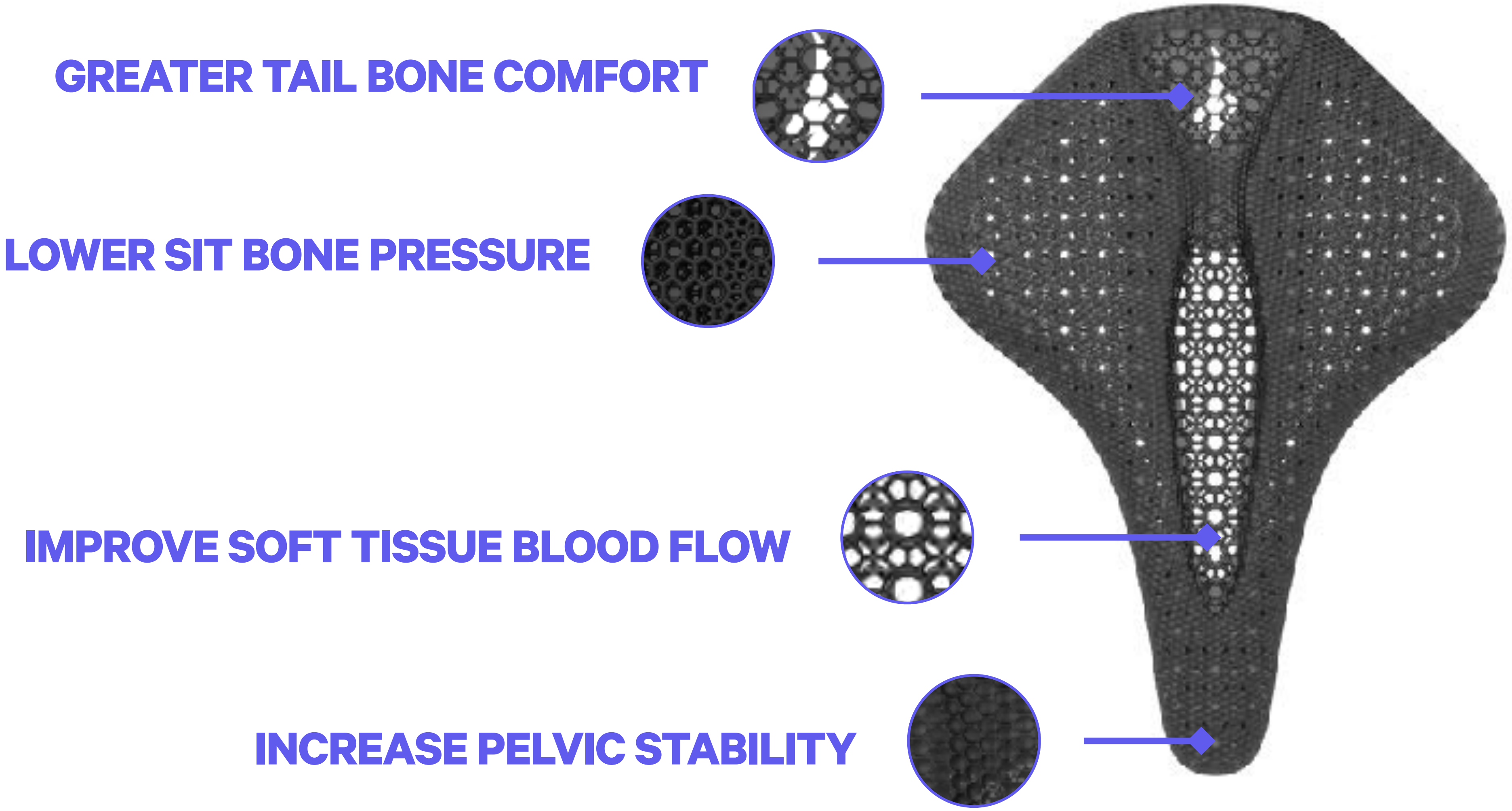
- Tailor-made tips ensure absolute support and improve the sound quality
- Customer scans their ear with a mobile device, computing more than 15 different measure points
- Analysis of the ear shape is converted into a 3D model
- Model is printed on a Carbon printer using SIL 30 material - biocompatible silicone that is tear resistant, washable and comfortable
- Personalization options such as engravings and texturing are available


SPECIALIZED

Specialized S-Works Power Saddle With Mirror:

Maximum pressure at the sit bones is 20% lower than foam

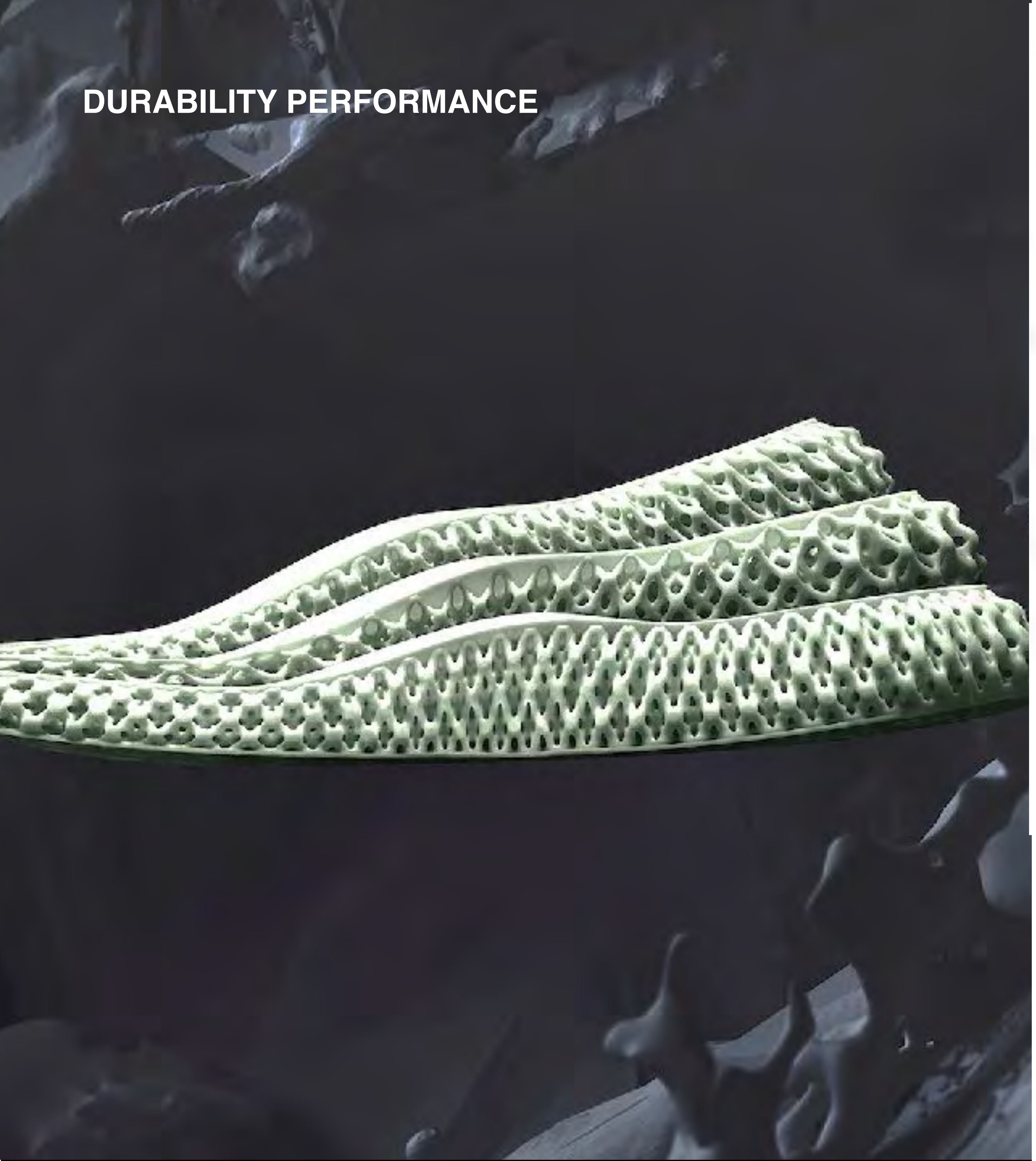


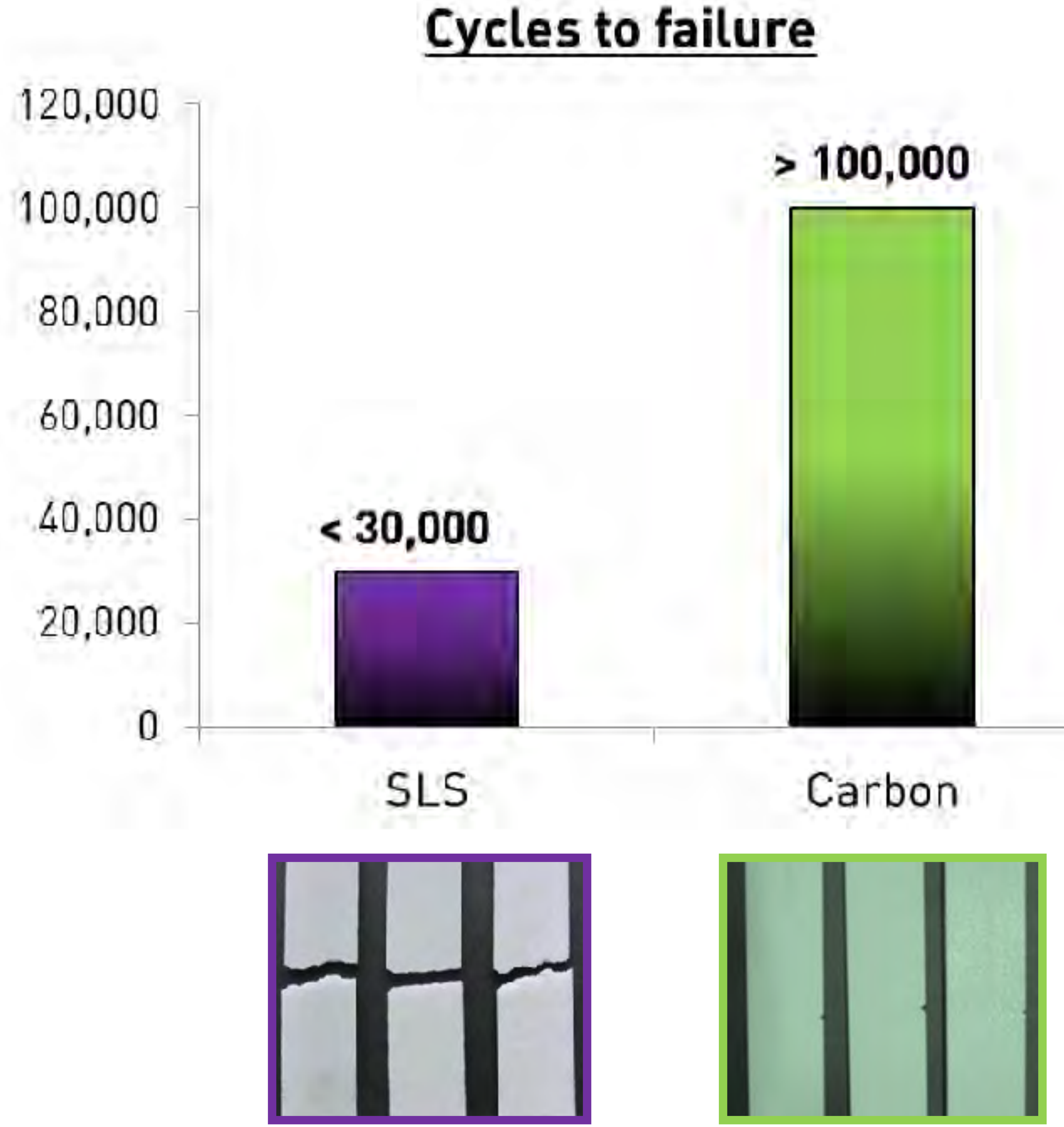


- 14,000 struts and 7,799 nodes orchestrated into a complex geometry to provide improved comfort and support
- Delivers a premium matte finish
- Reduced time-to-market by over 50% (from 24 months down to 10)

Performance Footwear

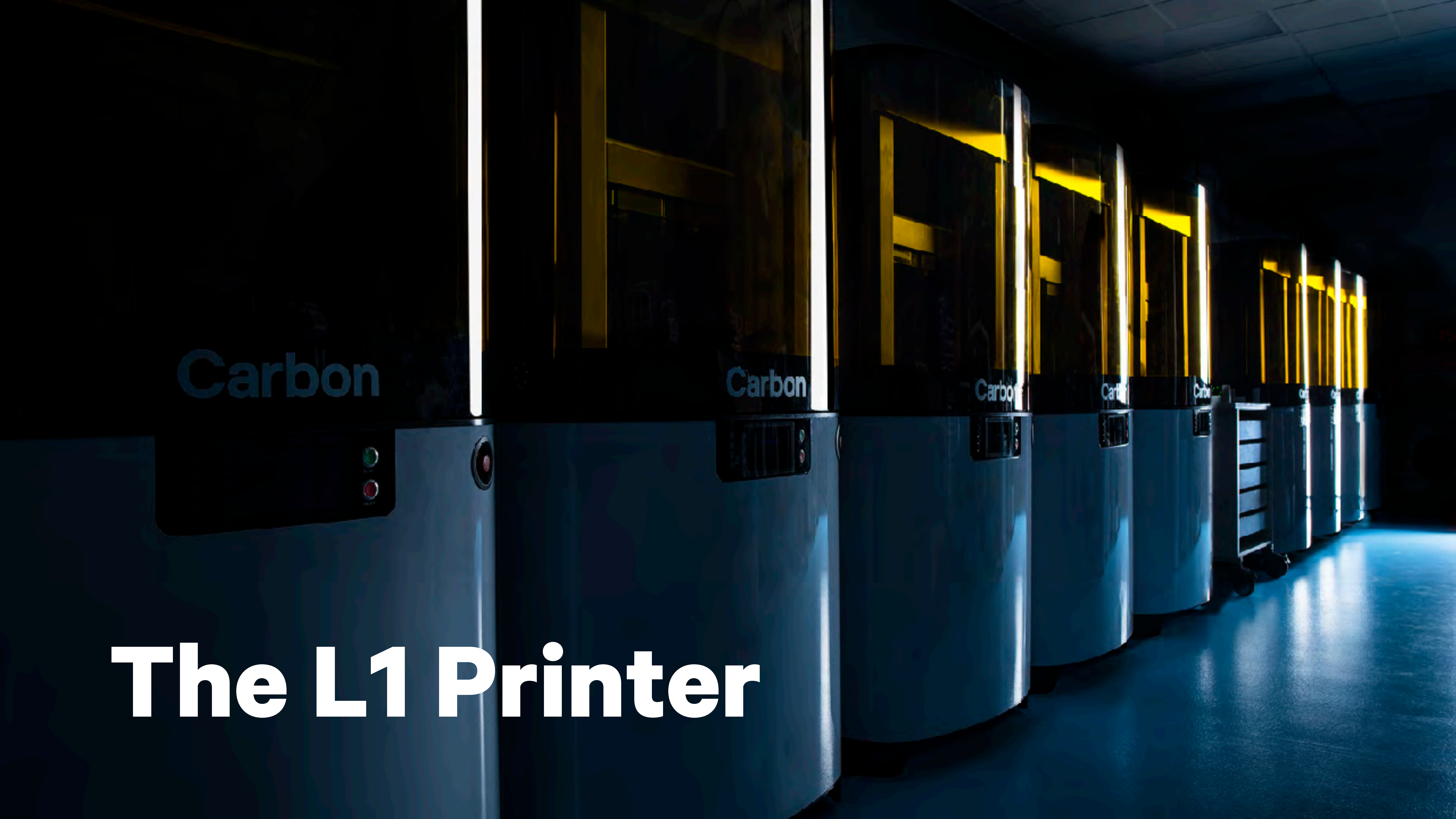
DURABILITY PERFORMANCE





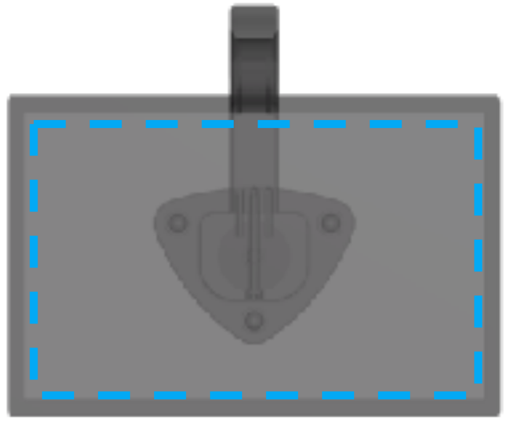
CRAFTED BY Carbon™

The L1 Printer



Carbon's Largest Printer to Date

~5x the build area of the M2 printer



M2 BUILD AREA

223 cm²

L1 BUILD AREA

>1,000 cm²

Dispense → Print → Clean → Bake

Dispense

Cartridges

Bulk meter, mix and dispense

Print

M2 Printer

L1 Printer

Clean

Washer

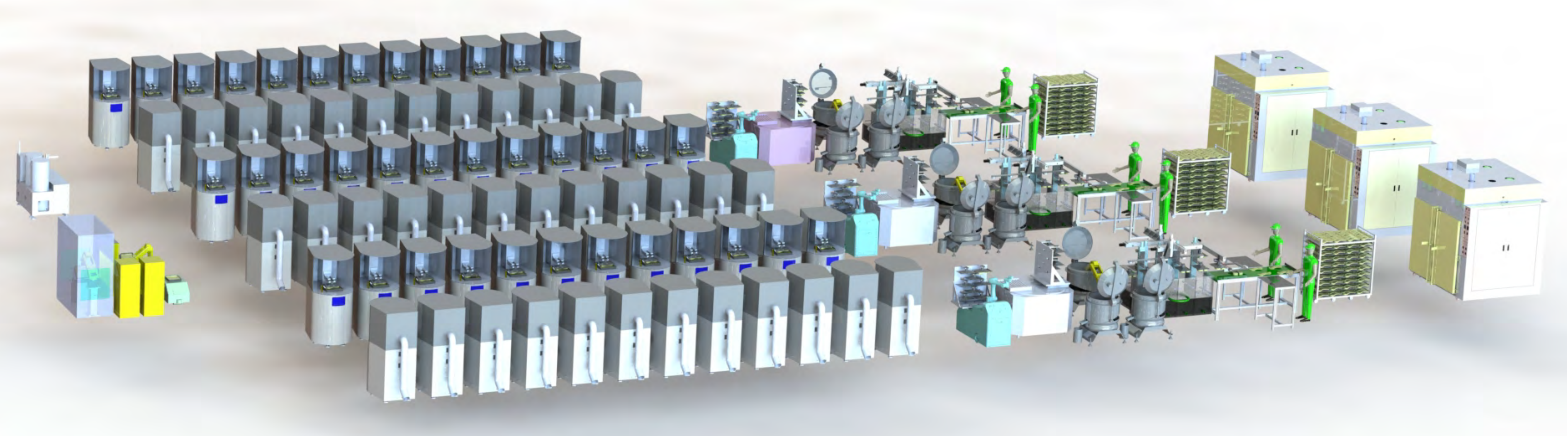
Solventless spinner

Bake

Bench top oven

Walk-in oven

Digital Factory of the Future




Carbon
Carbon

Carbon
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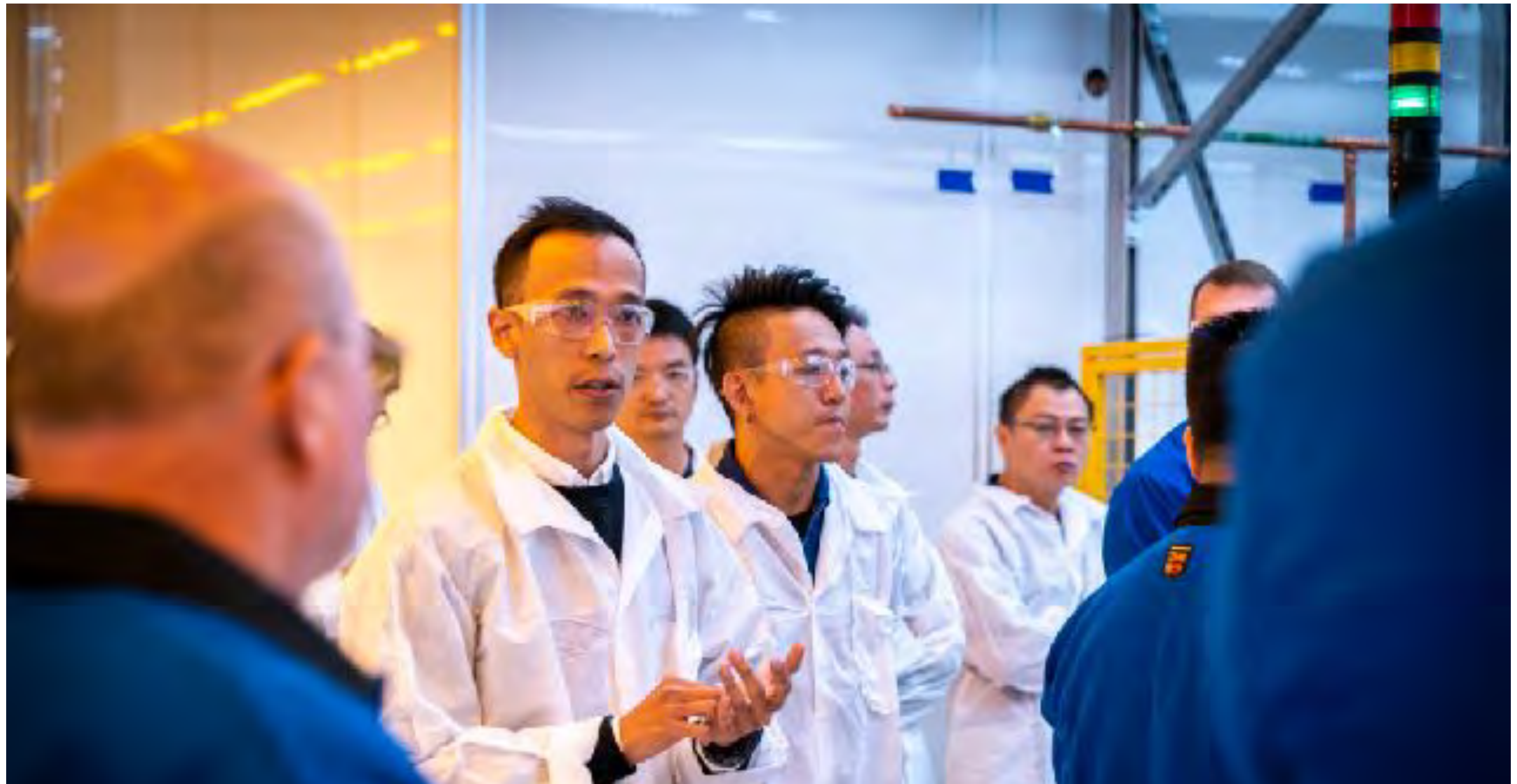
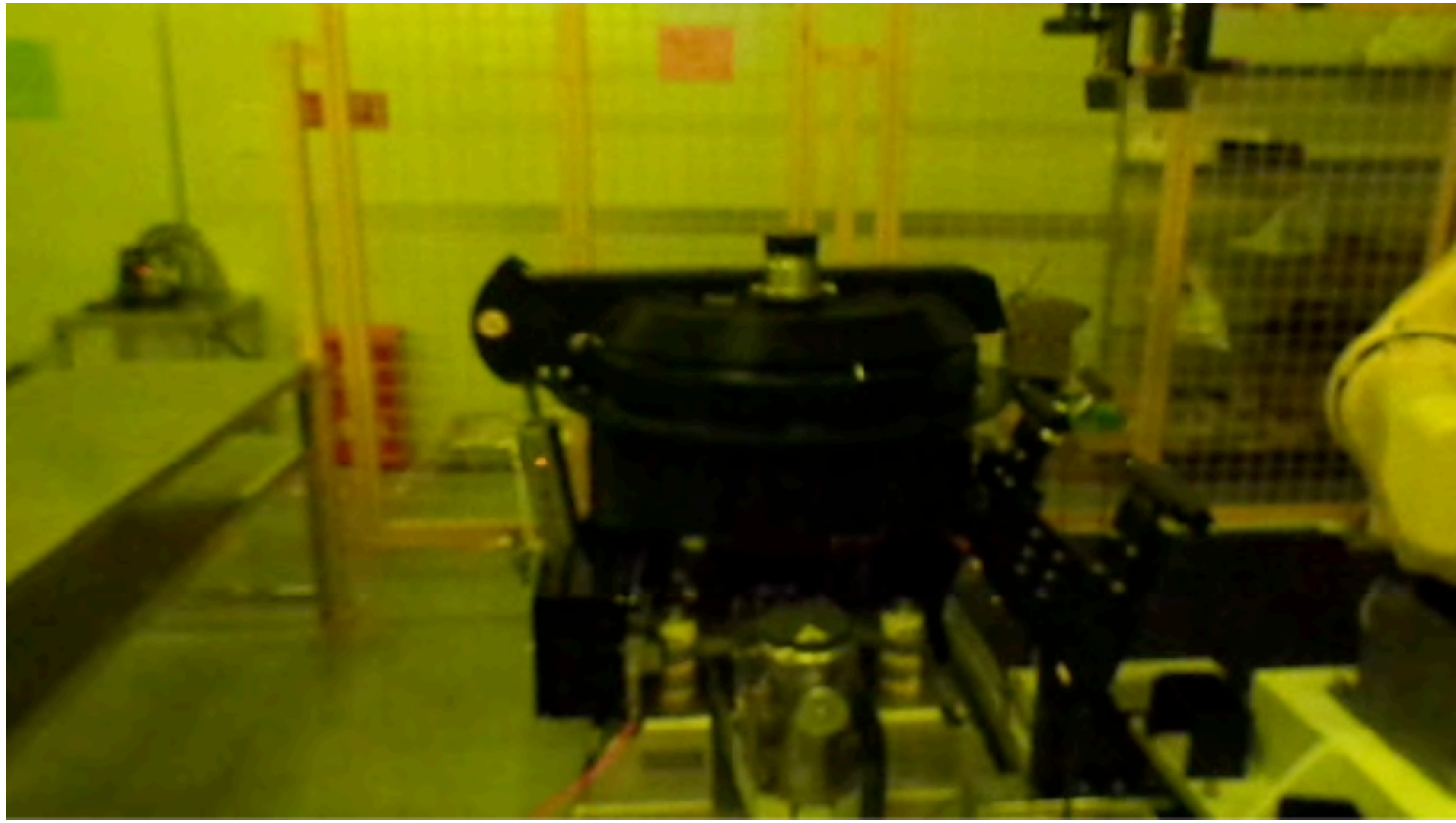




Carbon



AUTOMOTIVE LIGHTWEIGHTING

METAL → PLASTIC

PART SIMPLIFICATION

GLASS-FILLED → UNFILLED

Metal → Plastic: Ford’s First Additive Polymer Parts

Mustang GT500 Electric Parking Brake Bracket

Series production application

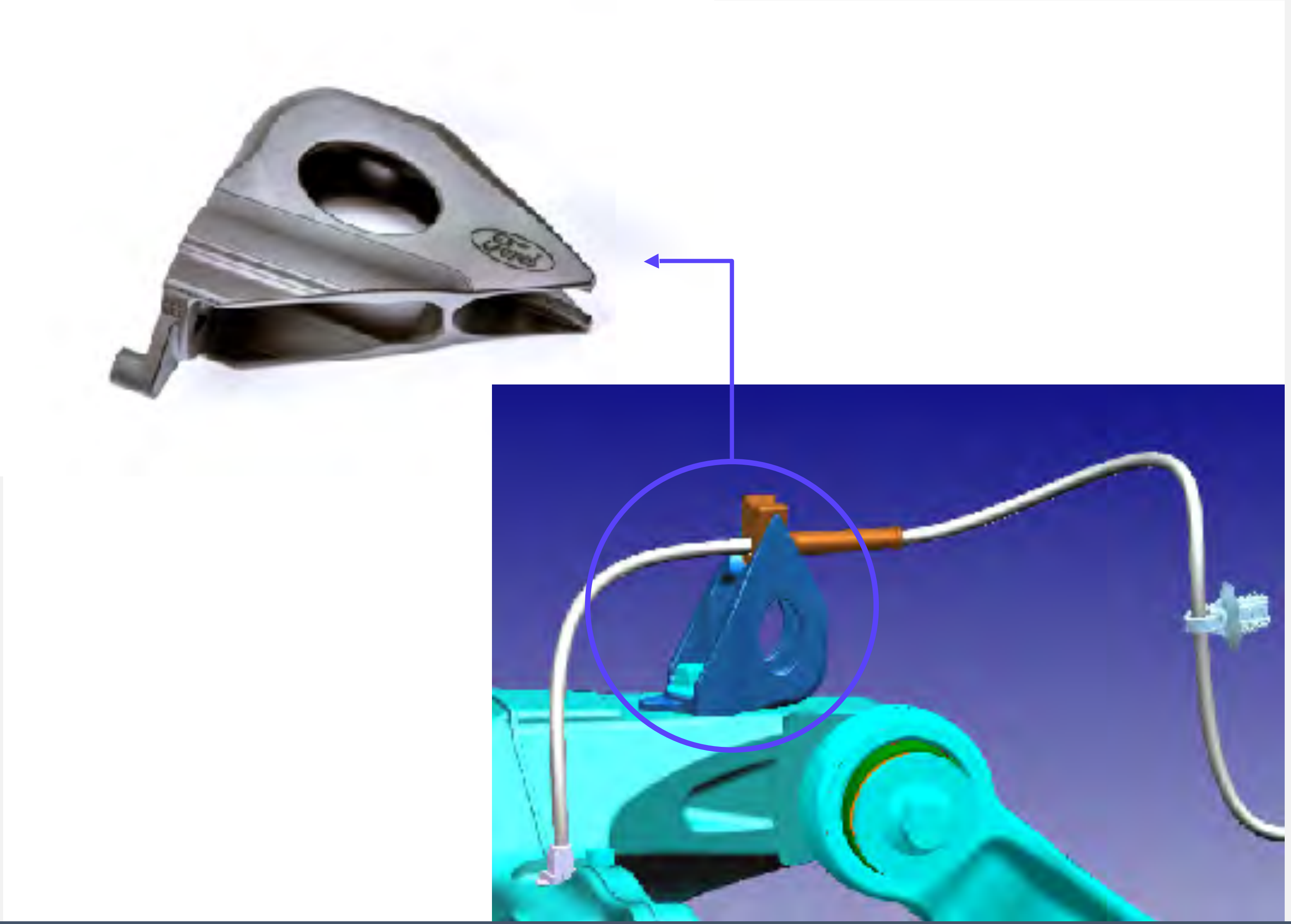
Metal to plastic conversion; **>60% weight reduction**

Cost savings compared to tooled part

Reduced complexity (RH/LH to mono design)

- improved installation
- address request from ergonomics team

Quick iterations and validation to improve design and performance



Reduced Weight and Improved Performance through Design Freedom

Part Design and Consolidation Enables Lightweighting

2020 Lamborghini Urus Gas Cap Cover

Design modifications enable **14% weight savings** compared to standard part

Multiple design **iterations** in three weeks

Customized aesthetic with logo and texture

Appearance **requirements met** without secondary coating

Agile Design and Production

Carbon and Lamborghini Expand Partnership to Digitally Manufacture Parts

KEY TAKEAWAYS:

- Reduced part lead time by 12 weeks for the Sián FKP 37.
- Carbon EPX 82 material passed high-standard testing related to Interior Flammability, Volatile Organic Compounds, Thermal Cycling, and Heat Ageing.
- Reduced overall time-to-market for leading automaker

"Moving forward we are putting more effort and resources on using additive manufacturing technologies for production of parts for Lamborghini vehicles, and in working with Carbon, we have found a partner that shares our vision for creating best-in-class products that push the limits of what's possible."

– Stefan Gramse, Chief Procurement Officer, Automobili Lamborghini

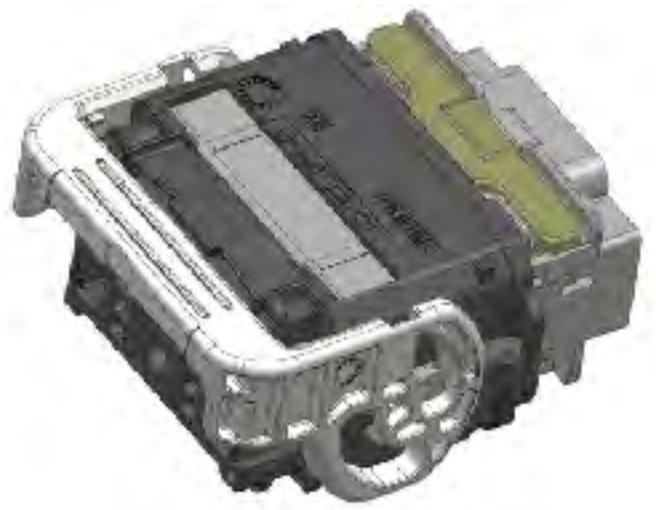
Glass-Filled Performance Without the Weight

High speed connector

Glass-filled PBT to EPX 82 enables **25% weight savings** on nominal part

Part re-designed to achieve **50% better terminal retention,** maintaining 2% weight savings

Simplified part design enables enhanced serviceability



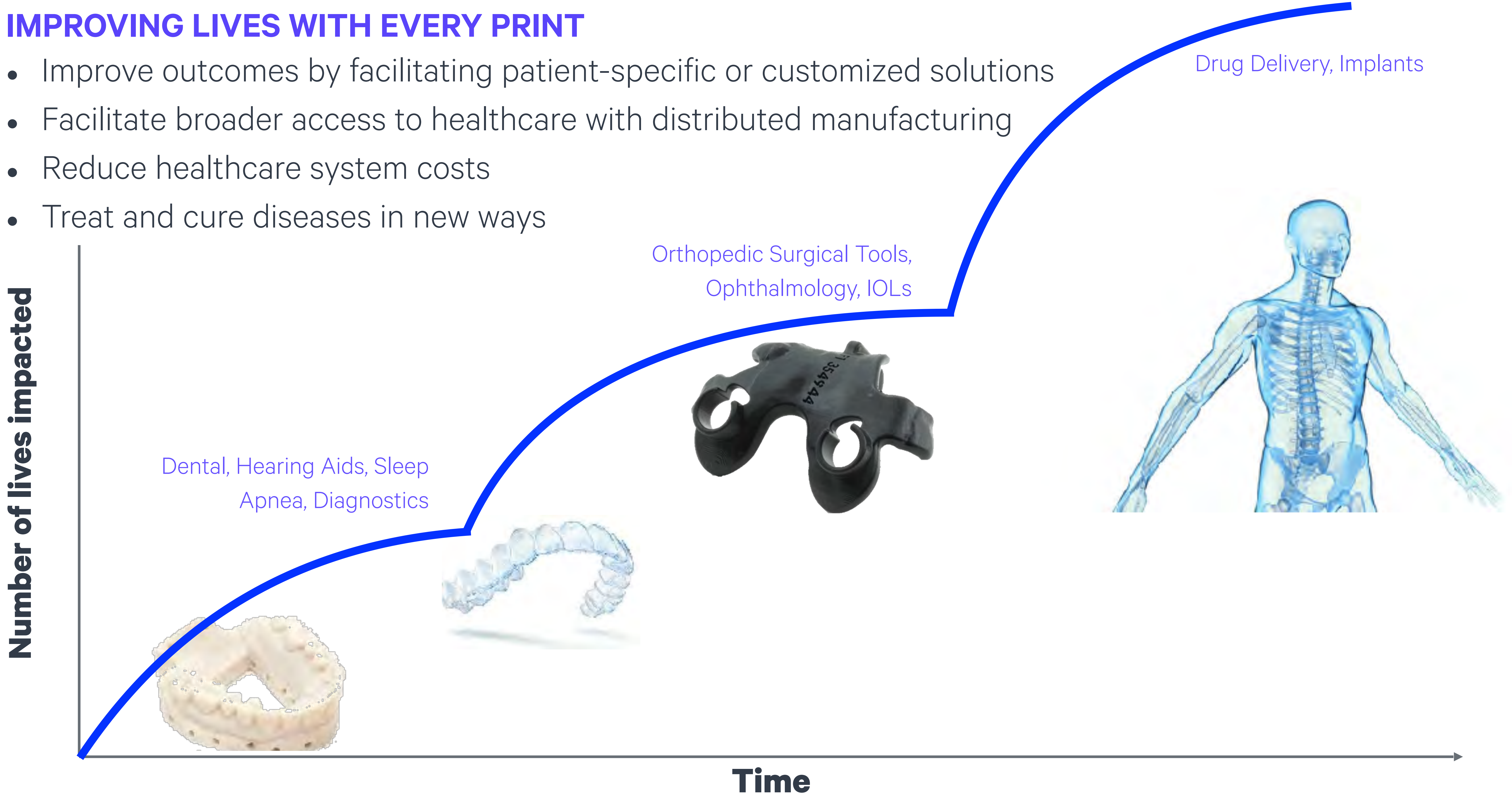
Injection Molded

Carbon DLS

Life Sciences Growth Strategy

IMPROVING LIVES WITH EVERY PRINT

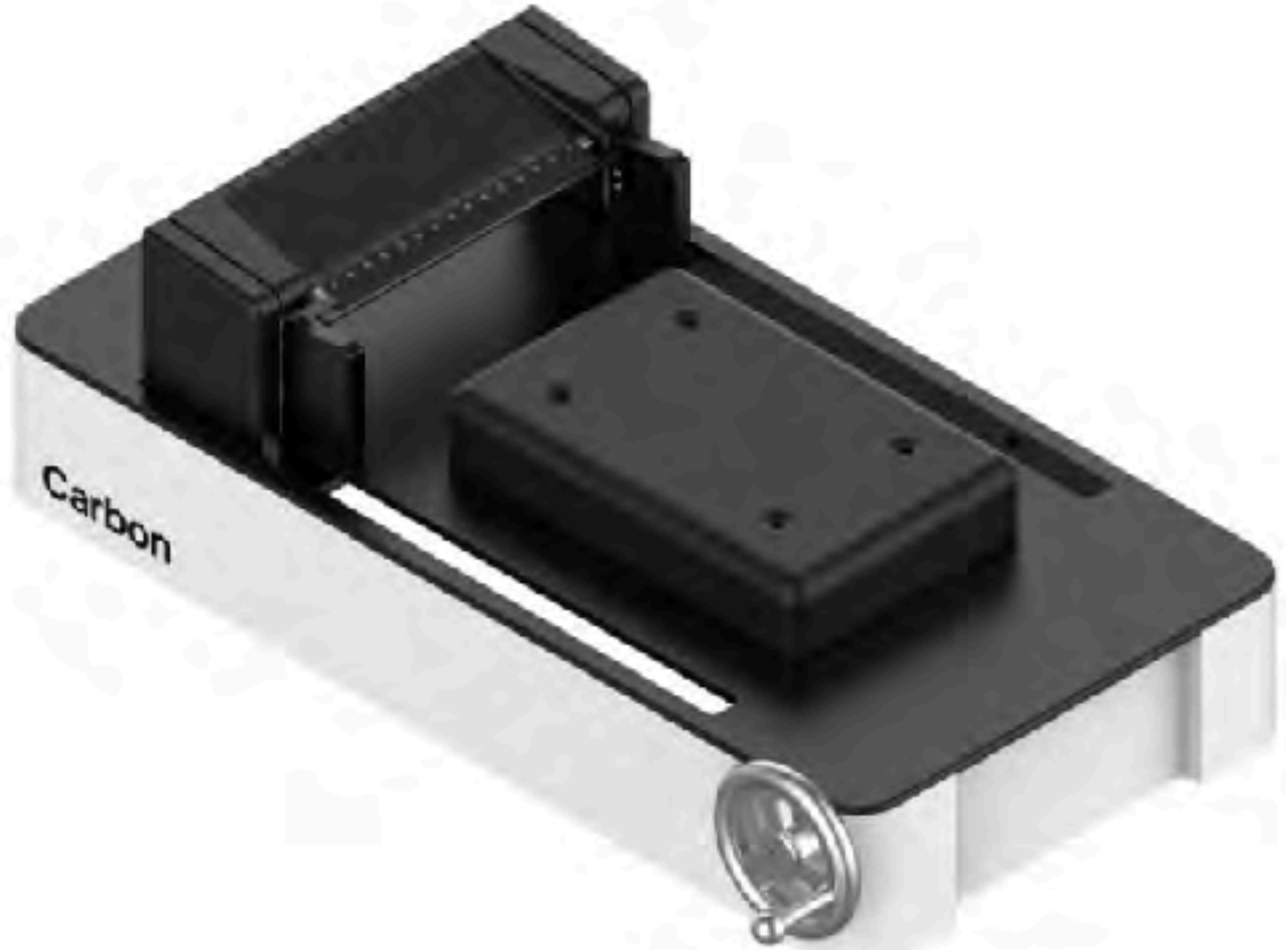
- Improve outcomes by facilitating patient-specific or customized solutions
- Facilitate broader access to healthcare with distributed manufacturing
- Reduce healthcare system costs
- Treat and cure diseases in new ways



Revolutionizing the Dental Industry

Thermoformed Aligners

Remove printed parts without a hammer and chisel



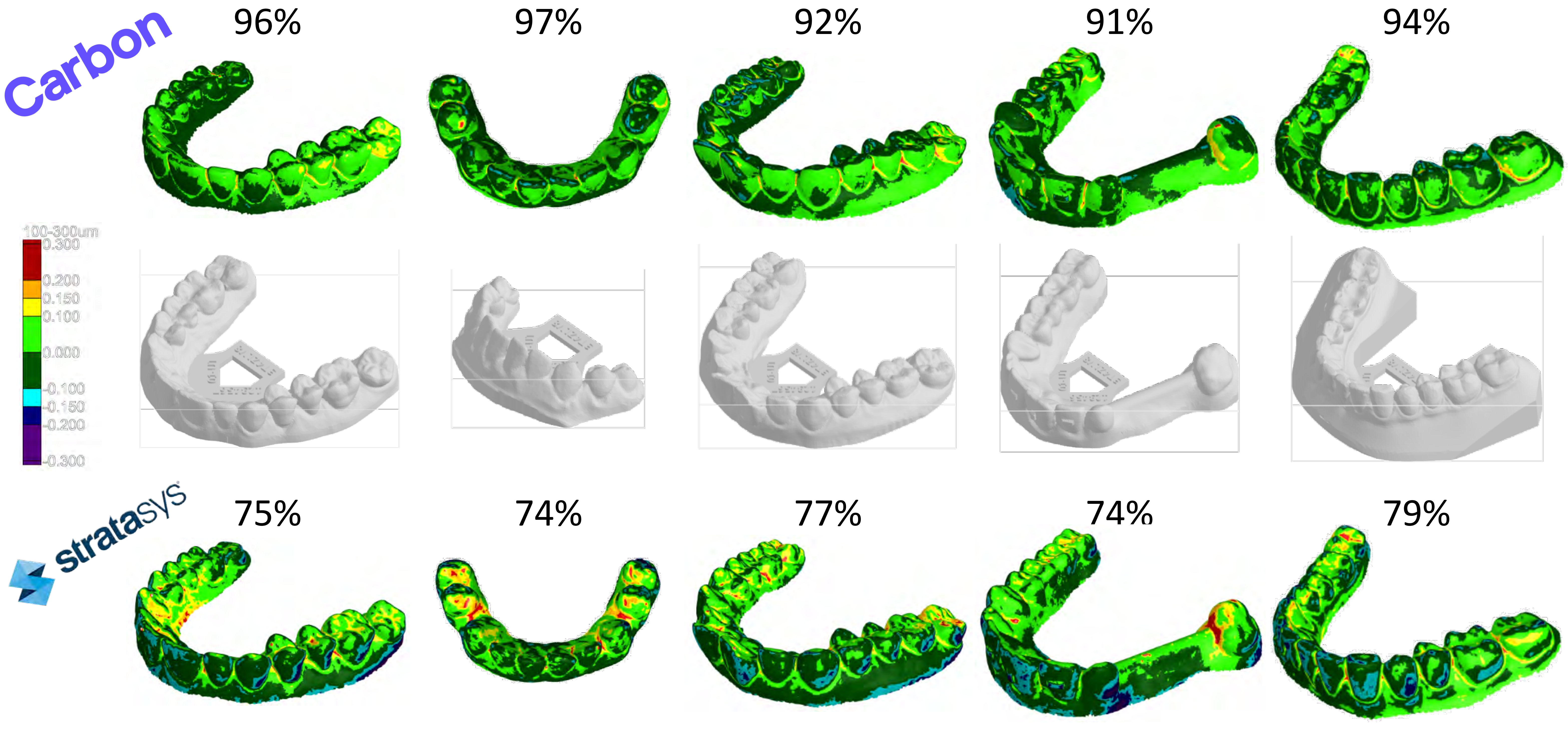
Simply peel off printed models from release film with Carbon's release film remover

1.

2.

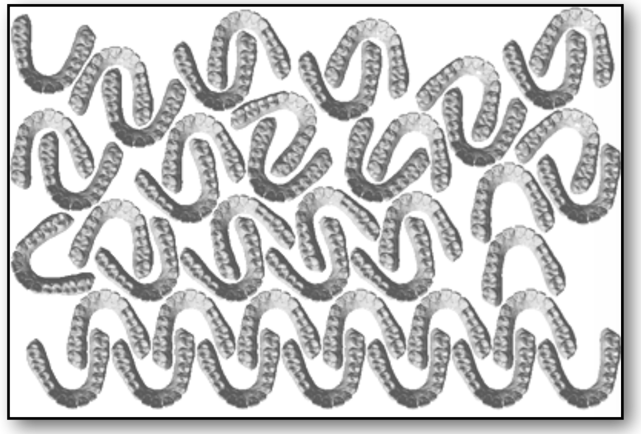
3.

Model Accuracy Comparison (% within ±100µm)



Carbon Manufacturing Cloud

Automating Workflow, Fleet Management, Digital Traceability



AUTOMATIC NESTING & PACKING

AUTO-QUEUING ACROSS FLEET

PROCESS INCOMING UNIQUE MODELS, 1000S/DAY

REAL-TIME ANALYTICS

UP-TO-DATE FLEET STATUS

Carbon’s Commitment to a Sustainable Future

PROBLEM

3.5 metric tons of dental models go to a landfill every day

OUR THINKING - REVERSIBLE THERMOSETS

- Can be **100% recycled** back to liquid components for future dental resin
- **20-50%** recycled content possible

Recovered resin components

Pulverized powder

Printed model


DENTURES

Categories of Tooth Replacement

Tooth Replacement is a $24B market

Full Dentures

$4.7B
2-4% CAGR

Implant Supported Dentures

$4.0B
7-9% CAGR

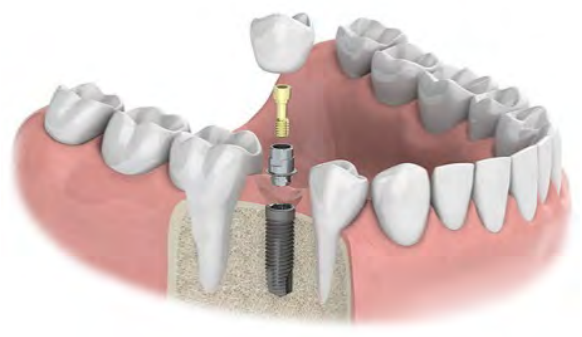
Partial Dentures

$6.6B
5-7% CAGR

Fixed Hybrid Dentures

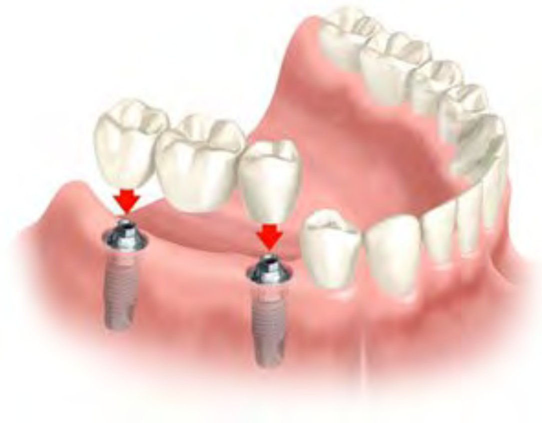
$1.6B
8-10% CAGR

Single Tooth Implants



$5.6B
9-10% CAGR

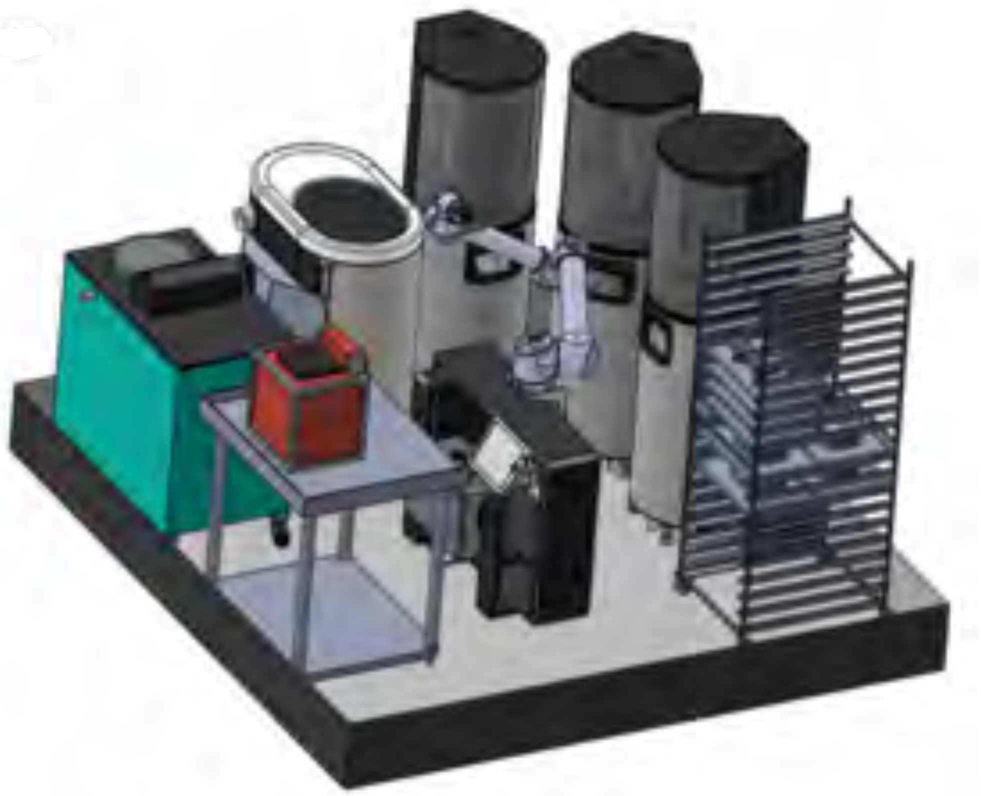
Multi-Tooth Bridge

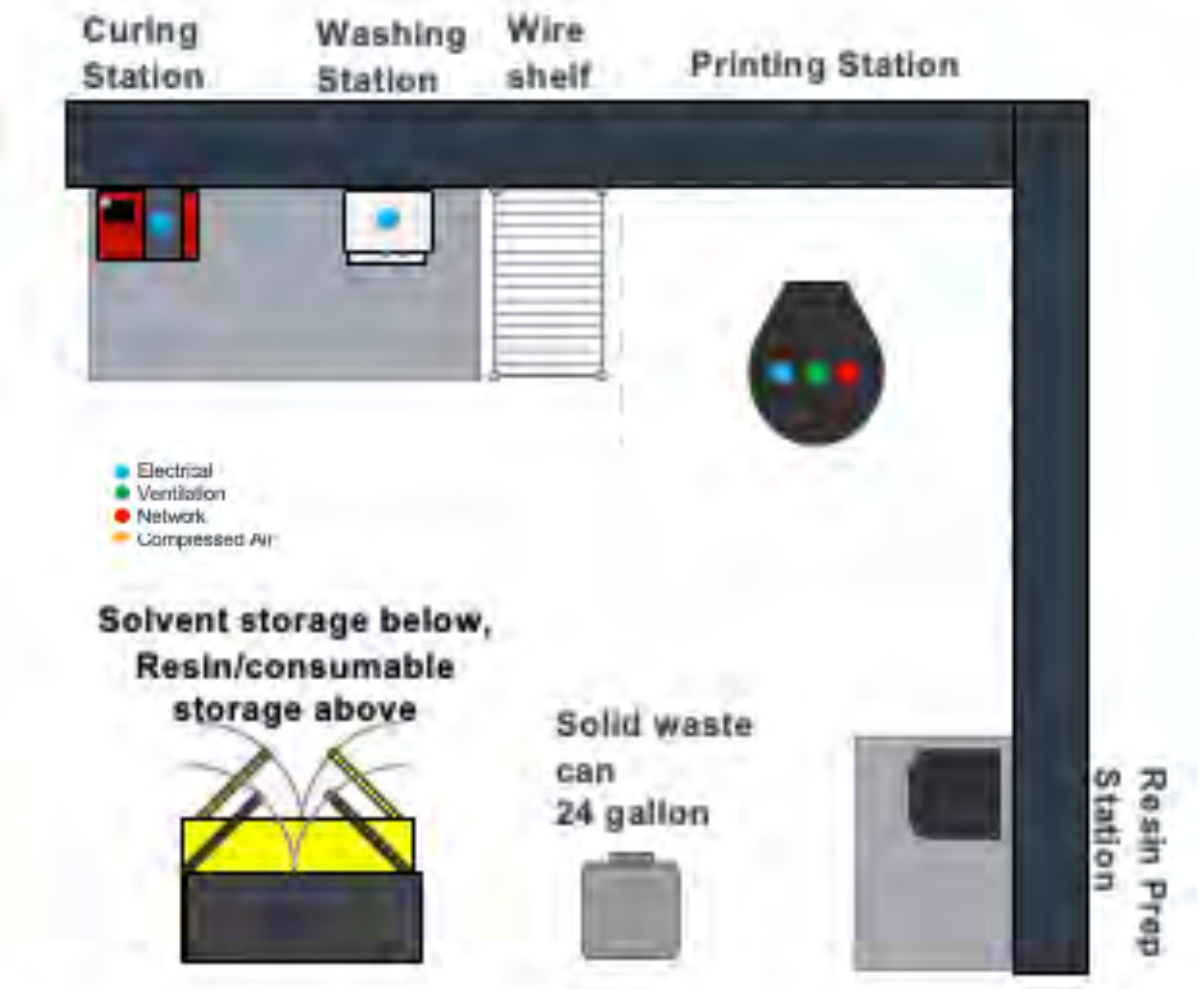


$1.5B
0-2% CAGR

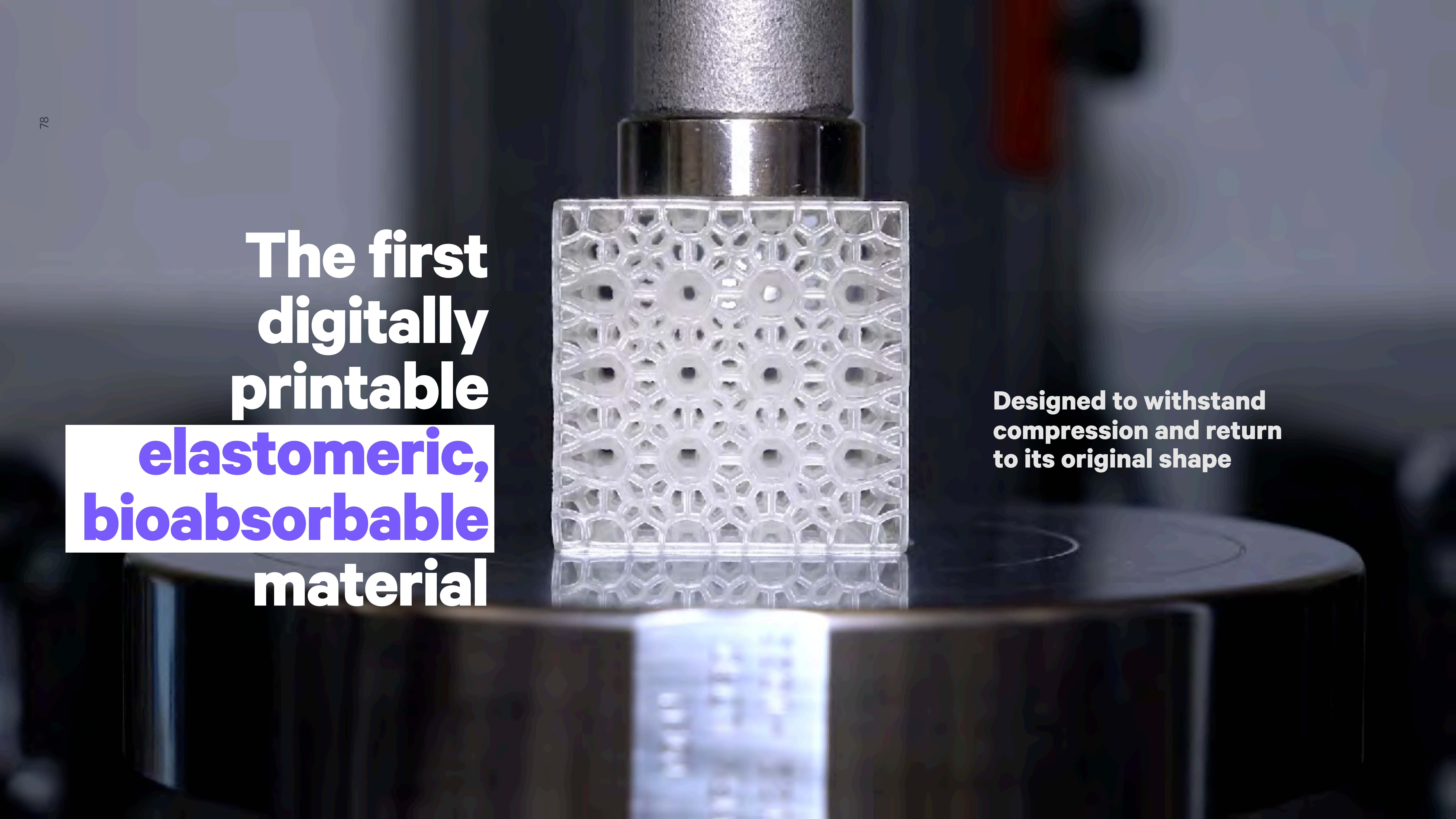
Source: Affordable Care Inc. 2019

Sample Clinic/Lab Rendering






Improved healing with new materials that can be safely absorbed within the body without a trace
Johnson & Johnson


The first digitally printable elastomeric, bioabsorbable material
Designed to withstand compression and return to its original shape

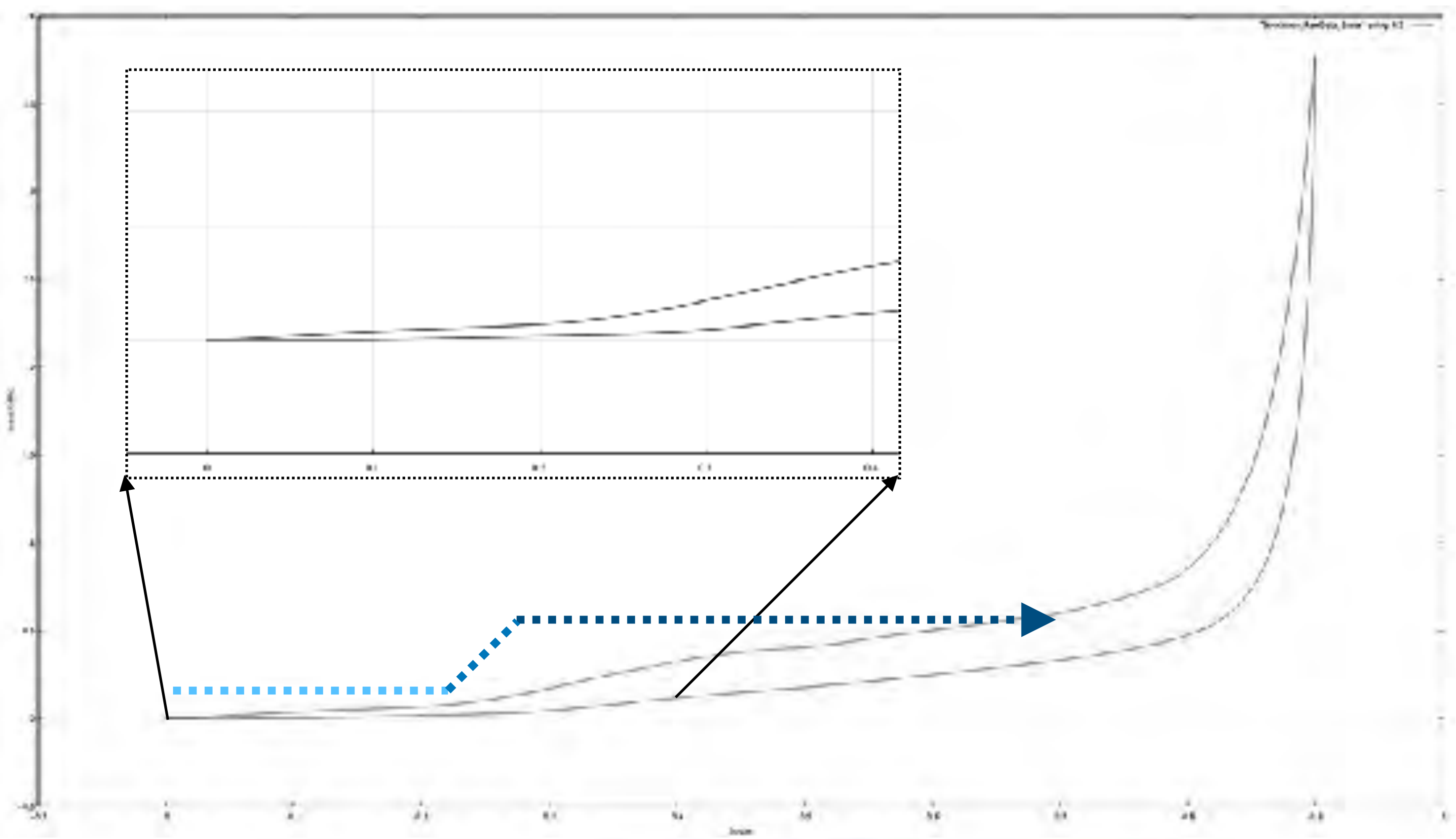
Demonstrated biocompatibility; sterilization compatibility

Biocompatibility	
Cytotox	• **PASSES**
Irritation	• **PASSES**
Sensitization	• **PASSES**
Acute Systemic Tox	• **PASSES**
Genotox	• **PASSES**
Implantation	• Results expected Q1 2020

Sterilization	
Gamma	• **Reasonable changes in mechanical properties** • **Passes genotox post-sterilization**
E-Beam	• Awaiting results
EtO	• Testing planned

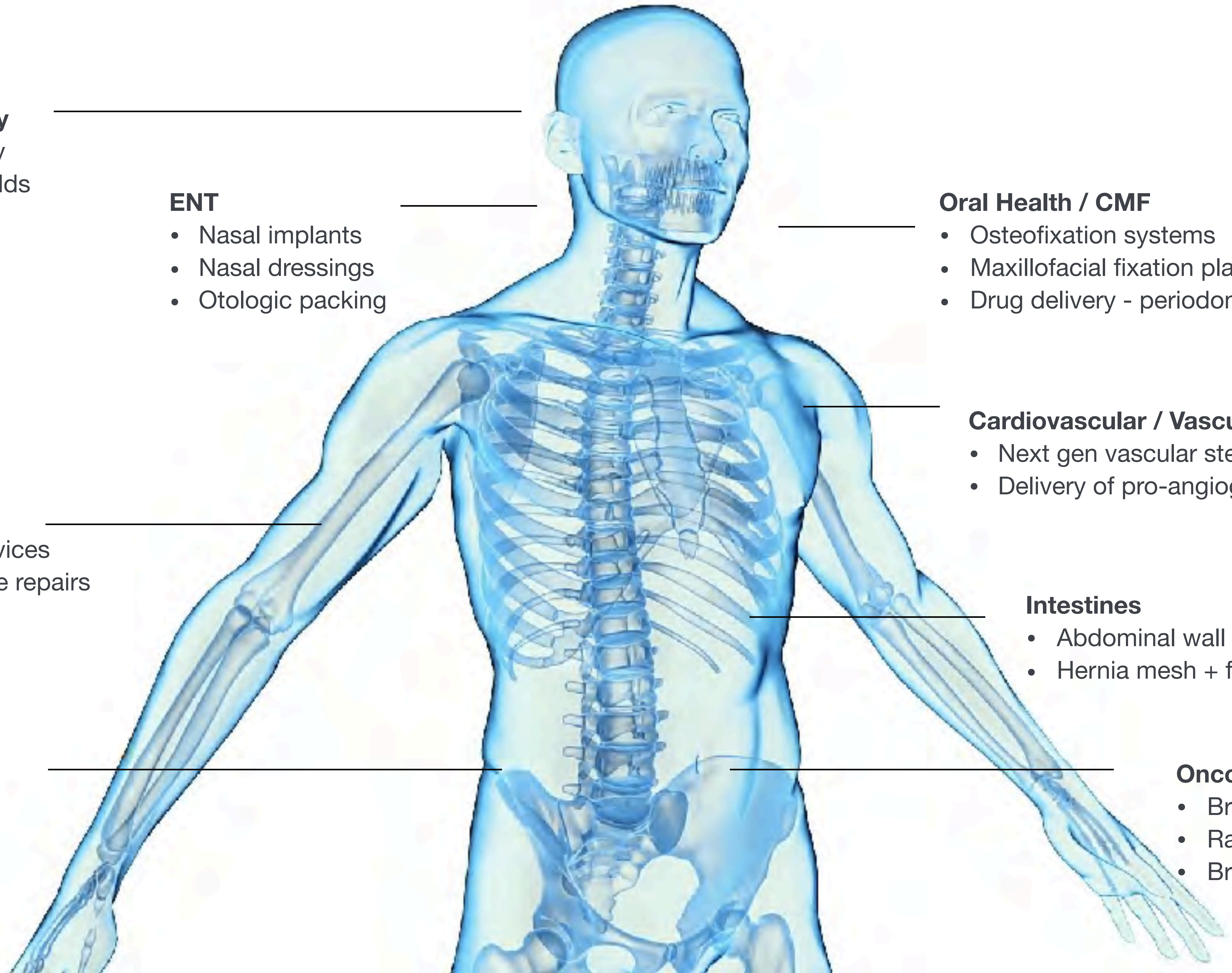
Controlling Strain Densification

- The design **adapts to the customized environmental loading condition** (patient specific head/tissue shape) with the same constant design.
- We can design parts where the densification can be **postponed up to 70%** strain at 50 kPA within < 5mm design space, **volume fraction ~ 0.25**
- **Staircase stress - strain:** we can mix and match structures and their transitions to achieve a complex mechanical response.
- Controlled **surface to volume ratio to control degradation.**



Carbon

Multiple Applications Representing Significant Unmet Clinical Need



Ophthalmology
- Drug delivery
- Corneal shields

ENT
- Nasal implants
- Nasal dressings
- Otologic packing

Oral Health / CMF
- Osteofixation systems
- Maxillofacial fixation plates
- Drug delivery - periodontal disease

Orthopedics
- Space fillers
- Antibiotic delivery
- Temporary fixation devices
- Augmenting soft tissue repairs

Cardiovascular / Vascular
- Next gen vascular stents
- Delivery of pro-angiogenic cytokines

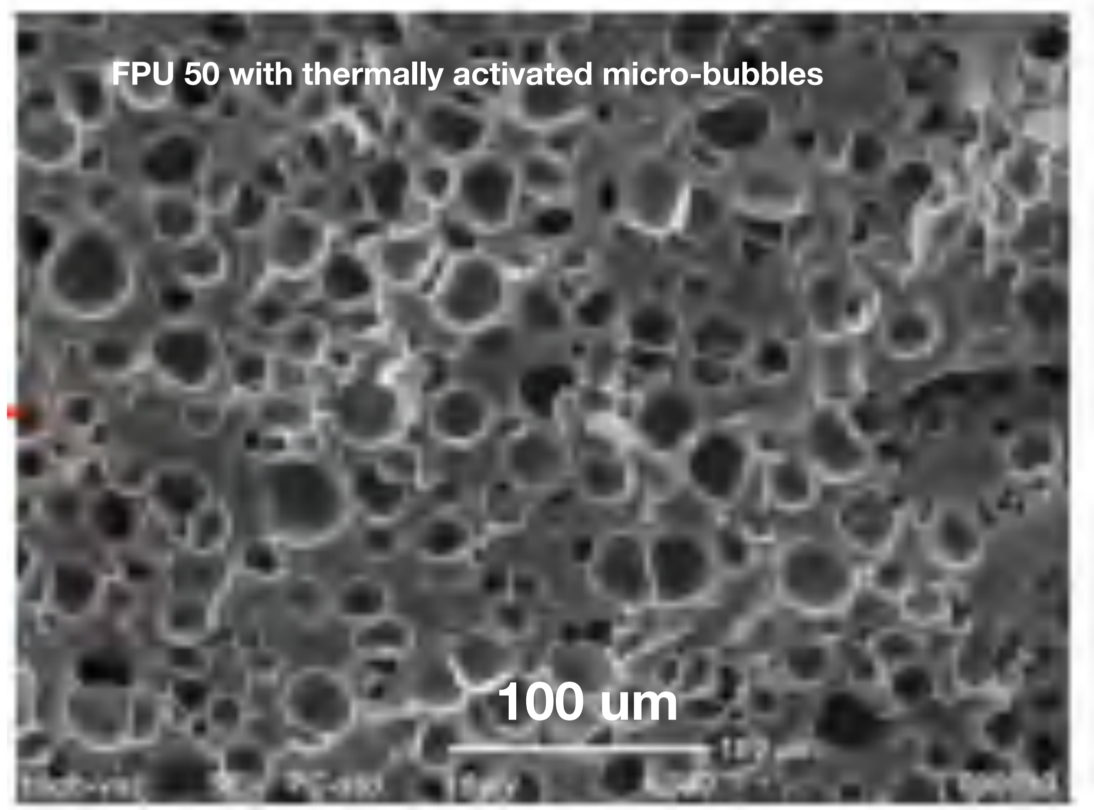
Intestines
- Abdominal wall repair
- Hernia mesh + fixation systems

Urology & Pelvic Health
- Surgical mesh
- Urethral slings

Oncology
- Brachytherapy endcaps
- Radiotherapy spacers
- Breast reconstruction

Controlled porosity to promote tissue restoration

Macro-scale: Lattice design



Micro-scale: Fillers & Poragens

Carbon's Bioabsorbable Product Pipeline

	Category	Feasibility	Preclinical Development	Regulatory / V&V	Commercializ-ation
Johnson & Johnson	Surgical Use (details not publicly disclosed)				
Carbon Product #1 (BE-EXS)	Cardiovascular				
Carbon Product #2 (BE-AHB)	General Surgery				
Carbon Collaboration Products	Seeking collaborations in multiple categories (Urology, ENT, CV)				

Surgical Mesh: Current Products Mismatched to Properties of Tissue

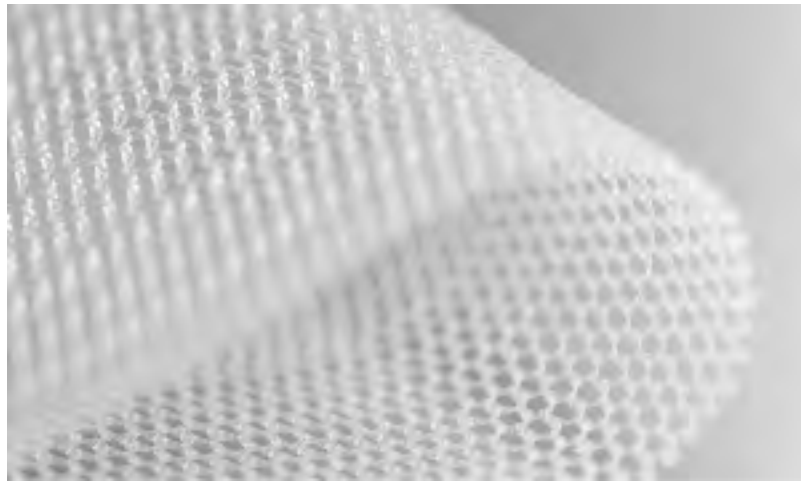
>20M HERNIA REPAIR PROCEDURES WW PER YEAR; >80% OF PROCEDURES USE MESH

RELEVANT PROCEDURES

- Hernia repair, 20M procedures per year (WW)
- Abdominal wall repair
- Breast reconstruction, 100k procedures / year (US)
- Thoracic wall defects
- Suture line reinforcement
- Muscle flap reinforcement
- Facial soft tissue defects
- Nasal reconstruction & septal perforation
- Urethral sling surgery*
- Pelvic mesh*

LIMITATIONS OF CURRENT PRODUCTS

- Infection
- Fibrosis
- Adhesions
- Mesh rejection
- Hernia recurrence

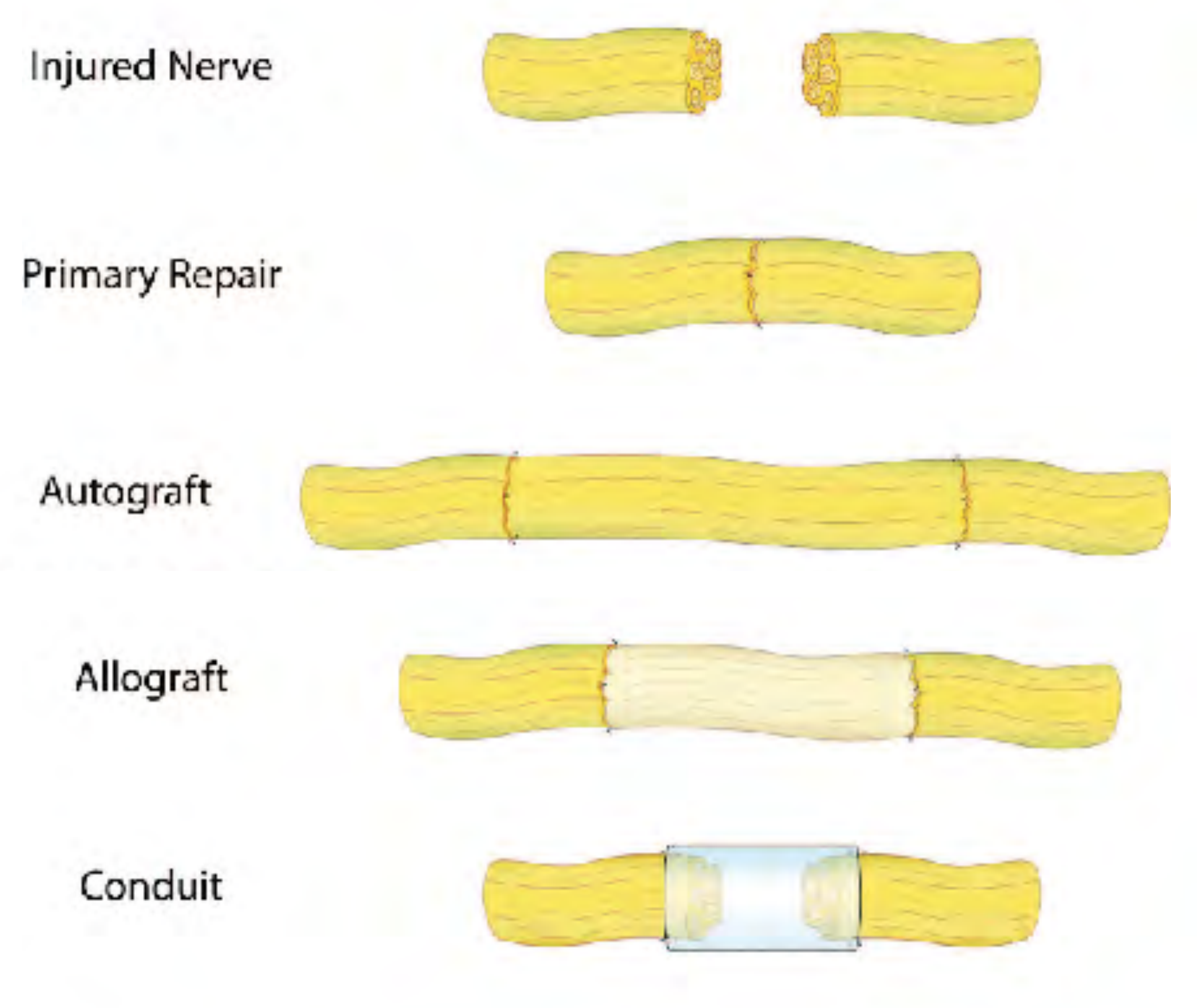


IDEAL PRODUCT IN MOST CASES IS AN ELASTIC, LIGHT WEIGHT MESH, WITH LARGE PORES, AND MINIMAL SURFACE AREA

* Current commercial products are the subject of litigation

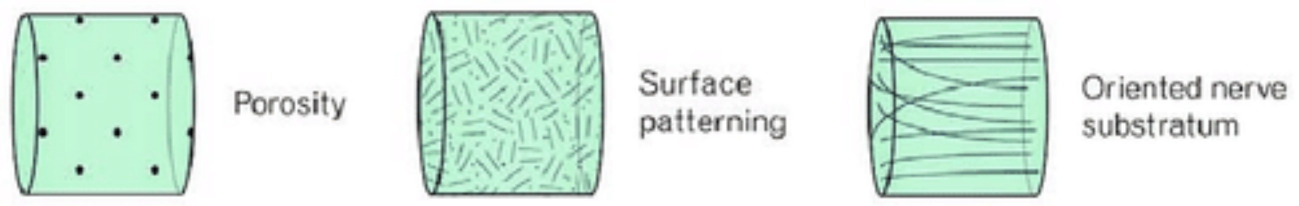
Source: “Past, Present & Future of Surgical Meshes: A Review,” Membranes, Sept. 2017

Nerve Conduits to Improve Treatment of Peripheral Nerve Injury



CARBON OPPORTUNITY

- **Controlled degradation rate** - sufficient time for nerve regeneration while avoiding encapsulation
- **Flexibility -** avoid damage to surrounding tissue
- **Porosity / permeability -** oxygen and nutrients
- **Micropatterning** - nerve guidance and regrowth



Source: Panayi, Adriana & Orgill, Dennis. (2018). Current Use of Biological Scaffolds in Plastic Surgery. Plastic and Reconstructive Surgery.

Conduit for Augmenting Soft Tissue Repair

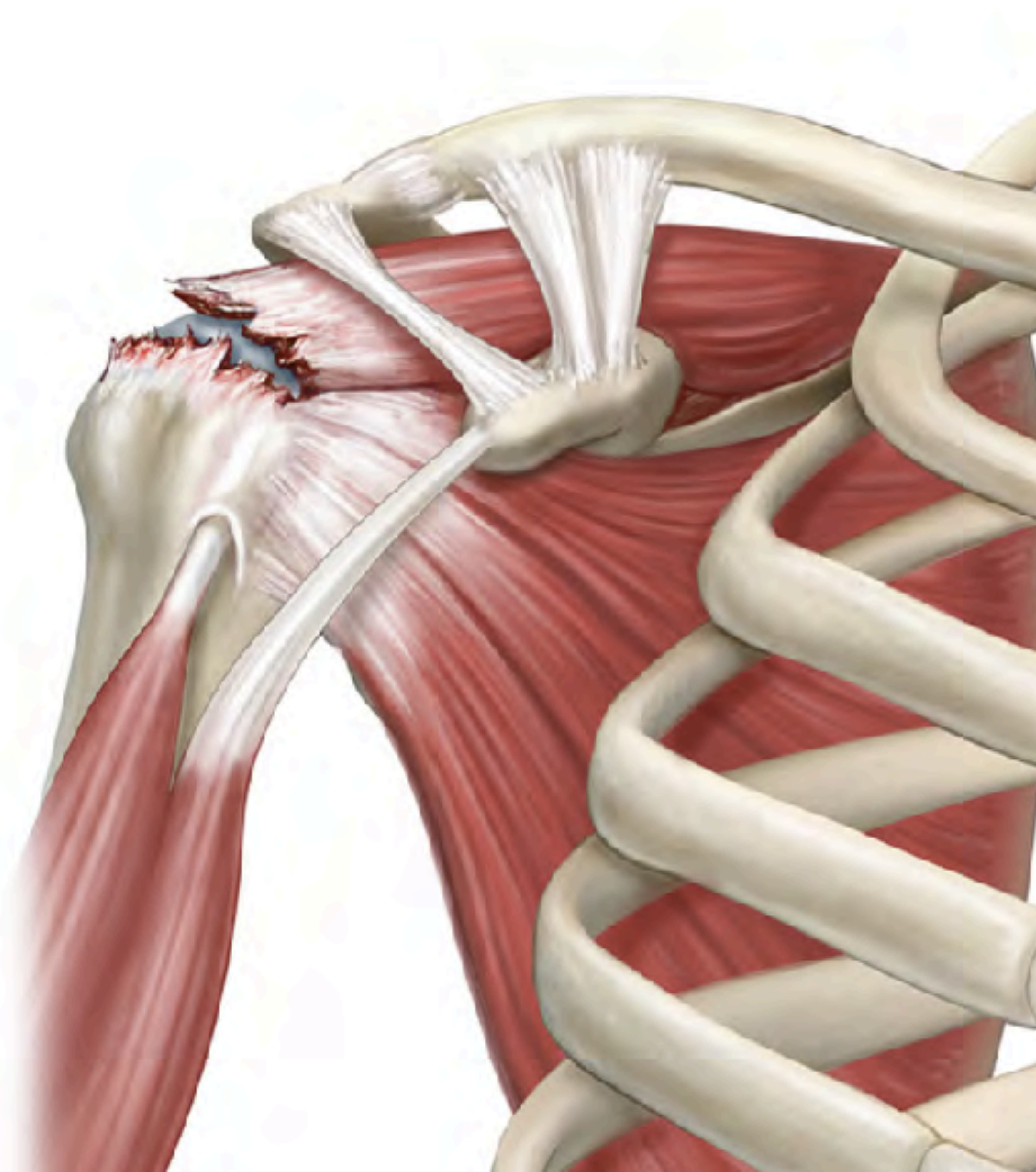
- **Rotator cuff repair:** 200 - 600,000 surgeries per year
- **Achilles tendon injuries**: ~1M per year

LIMITATIONS OF XENOGRAFTS / ALLOGRAFTS

- Foreign body / inflammatory response
- Insufficient “springiness”
- Inconsistency in mechanical properties

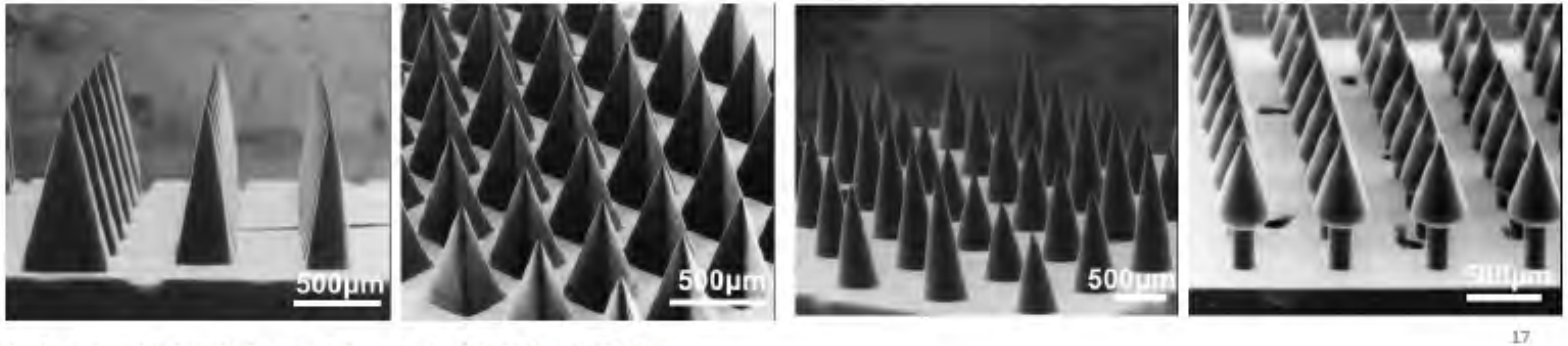
CARBON OPPORTUNITY

- **Consistency & tunability** of mechanical properties
- **Elastomeric** “springy” material
- **Potential for lower risk of foreign body response** compared to xenograft or allograft conduits

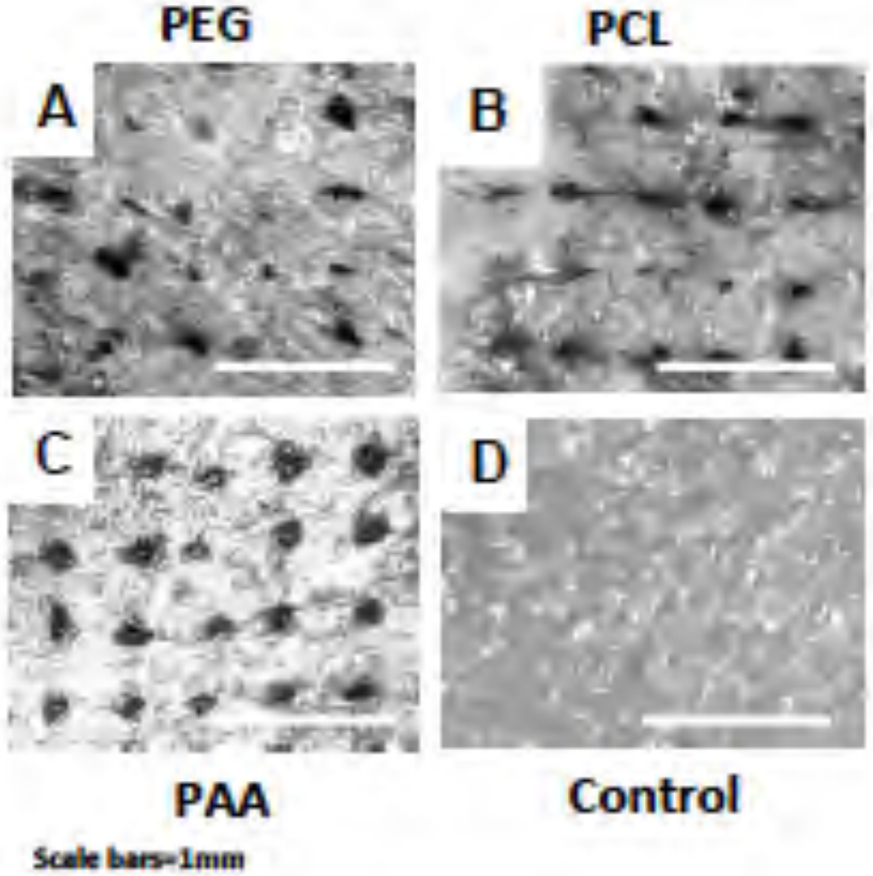


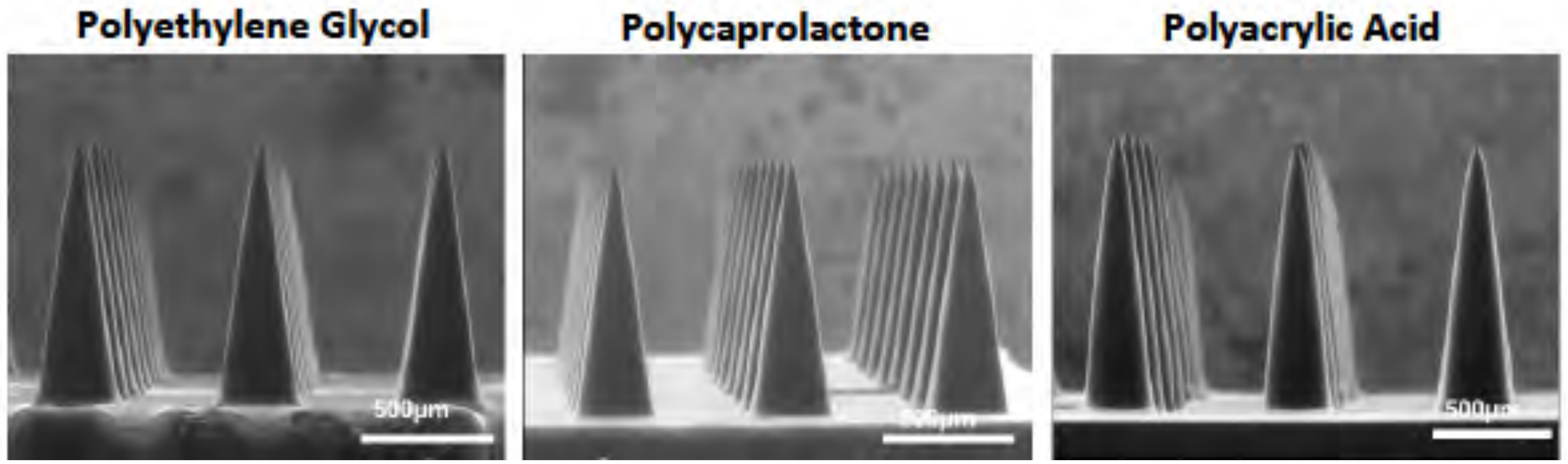
Local Drug Delivery

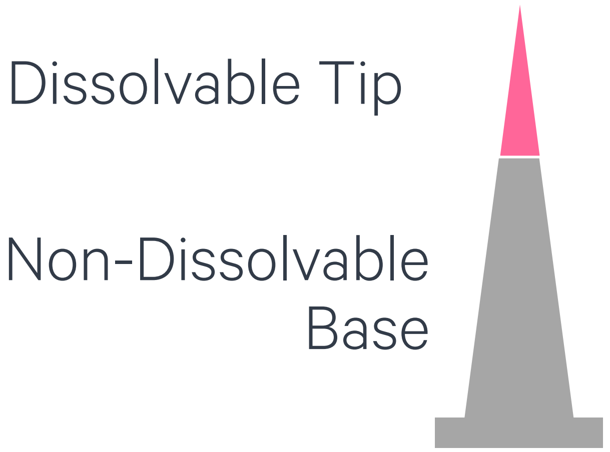
TRANSDERMAL DRUG DELIVERY VIA MICRO-NEEDLES

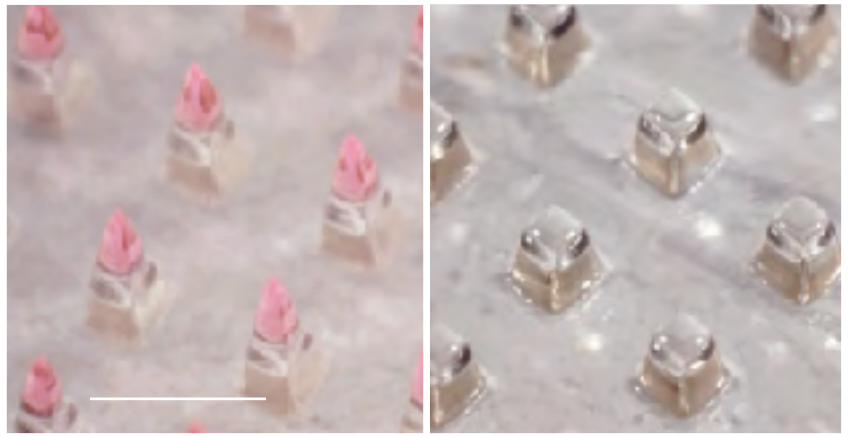


Tumbleston et. al (2015), *Science* ; Johnson et. al (2016), PLOS One.



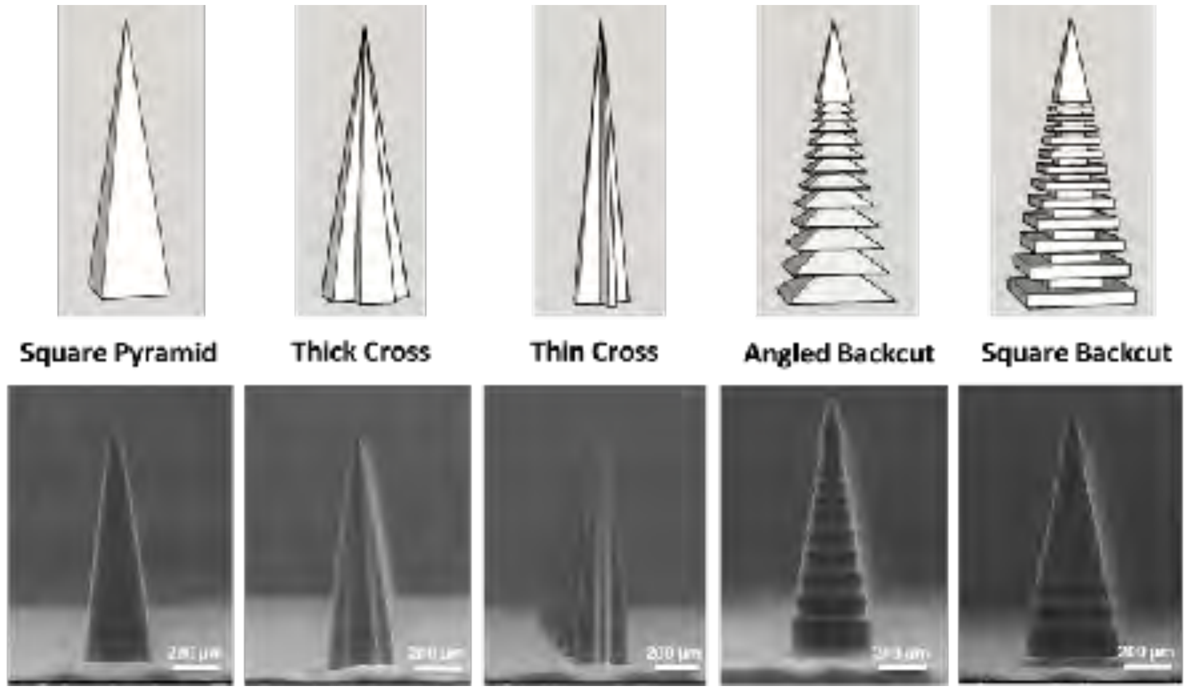


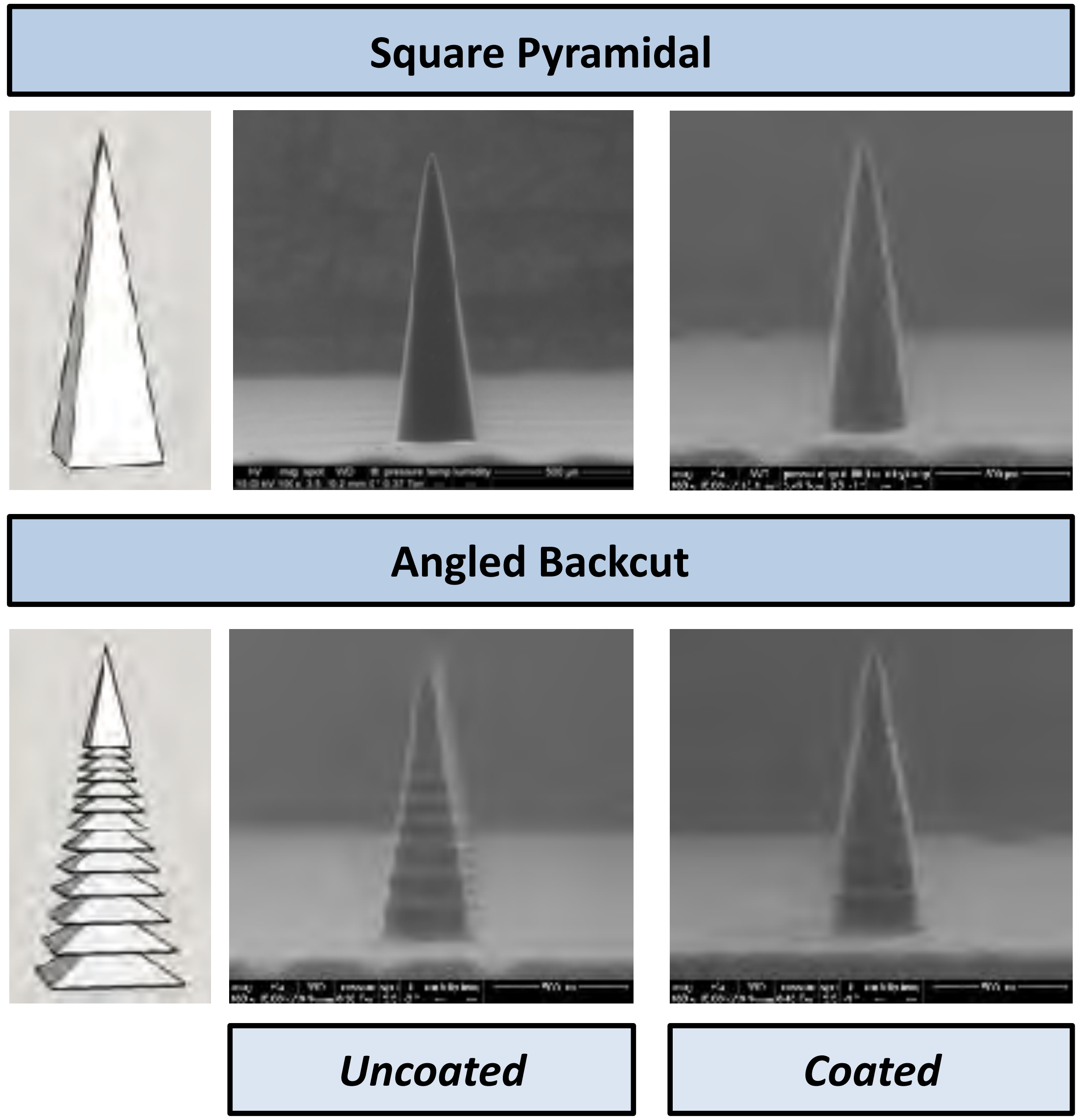




Microneedles with Novel Geometrical Designs to Improve Cargo Loading

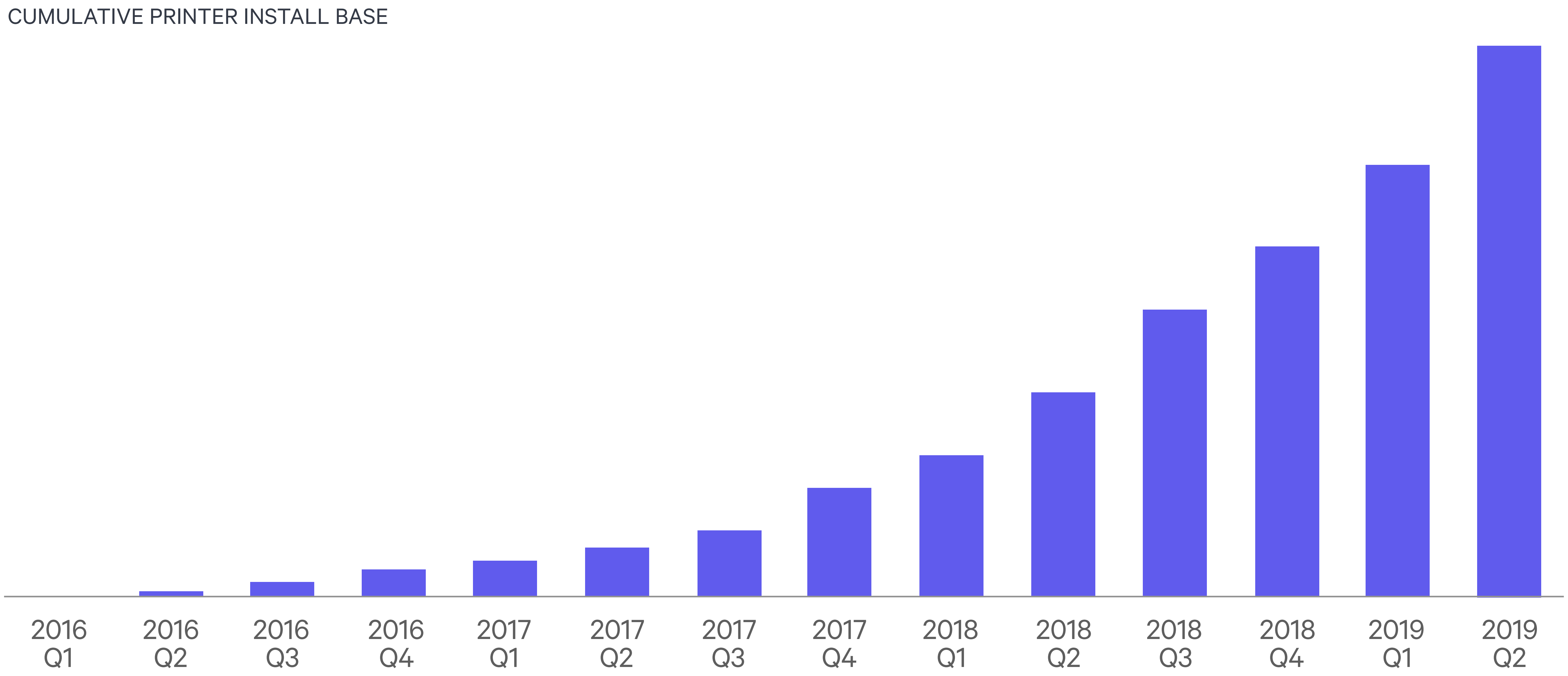
Hypothesis: MN designs with larger surface area potentially be coated with more cargo





Backcut MN demonstrated higher protein loading than square pyramid MNs

Approaching 1,000 Printer Installed Base



Innovative Business Model

HYBRID SAAS SUBSCRIPTION MODEL

adidas | Vitamix | BD | Ford | Riddell | AFFORDABLE DENTURES & IMPLANTS | SPECIALIZED

Carbon®

A Future Fabricated with Light